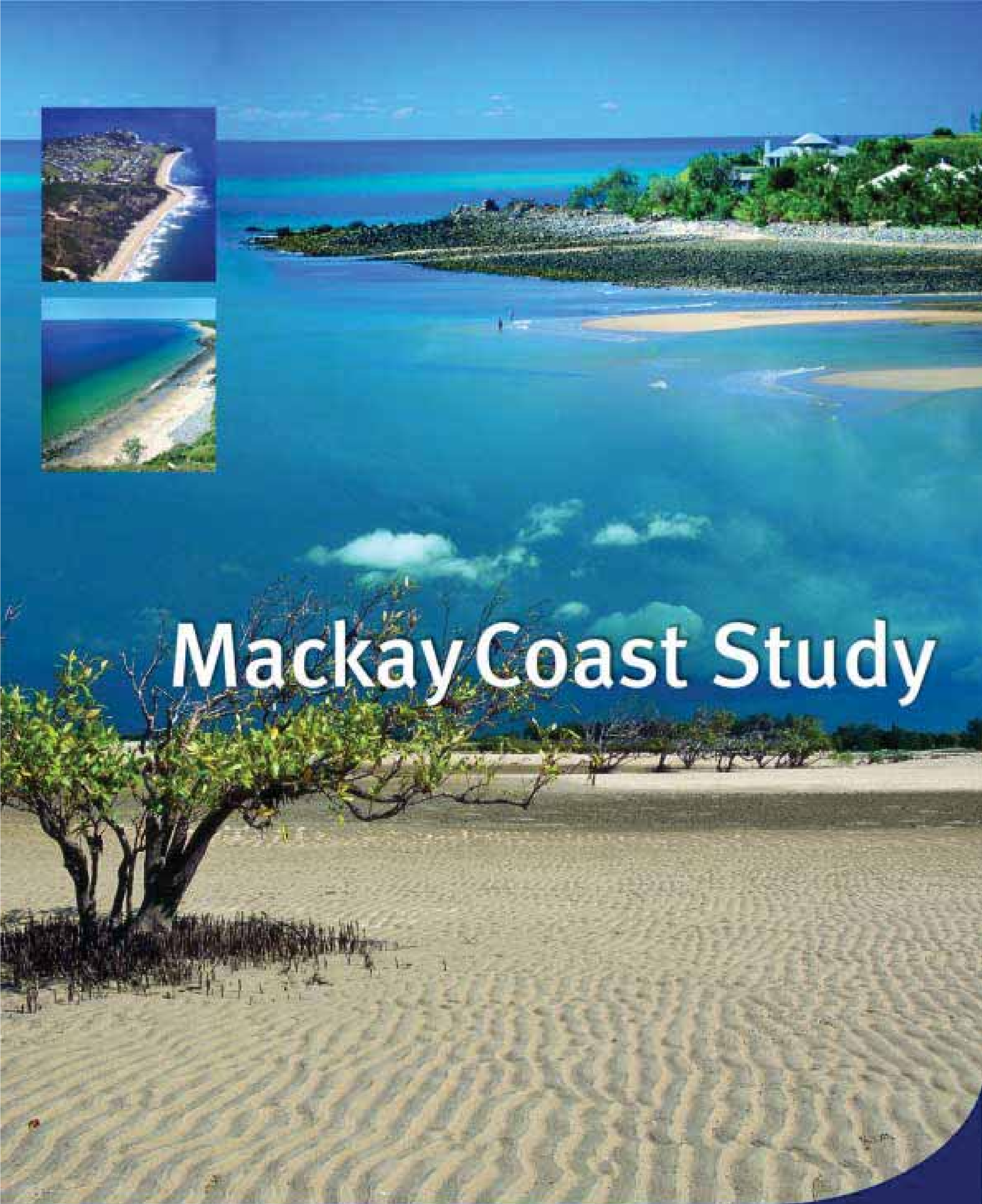

Mackay Coast Study

Queensland Government
Environmental Protection Agency
Queensland Parks and Wildlife Service

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Executive Summary

The Mackay coastal region is characterised by a range of diverse natural features, including:

- a large tidal range, exceeding six metres;
- a network of sandy beaches including high dune systems;
- the Pioneer River estuary;
- substantial areas of coastal wetlands supporting significant remnant lowland habitat; and
- extensive tidal flats, up to four km wide in some locations

The Mackay Coast Study was undertaken for the former Beach Protection Authority as part of its charter to provide advice and carry out investigations with respect to coastal management. This report examines the 40km section of coast from Bakers Creek to Shoal Point, to review and document the coastal resources and to describe the major coastal processes of the region. A number of general and site-specific recommendations are developed to guide future coastal management decisions.

Site-specific investigations were undertaken for the study, these include:

- data collection and assessment of coastal geology and soils, including a review of the geological history of the region;
- mapping of major vegetation associations;
- data collection and analysis of waves, currents, beach sediments and beach profile surveys;
- numerical modelling of wave propagation, tidal hydrodynamics and sediment transport;
- assessment of available data relating to significant fauna and coastal habitats; and
- review and analysis of meteorological conditions.

The principal findings of the study are focussed on issues relating to physical coastal processes. This includes a review of erosion prone areas for the region.

A number of areas of active coastal recession that may require management actions have been identified. These include parts of Far Beach and the northern section of Harbour Beach. The latter is the result of the combined effect of the Mackay Harbour breakwaters and the permitting of commercial sand extraction.

Along many parts of the Mackay coast, development has been allowed within the erosion prone area. This has led to the construction of protective rock walls and the associated adverse effects on the adjacent beaches. These areas, along with other low-lying suburbs set back from the shoreline, are subject to the risk of storm tide inundation. An important management response against the threat of coastal erosion and storm tide flooding is the maintenance of the natural protection afforded by the primary dune system.

It is concluded that coastal resources in the Mackay region are highly sought after for competing uses including residential, commercial, tourism and recreation. Effective management is necessary to ensure that the natural values and attributes of the coast are preserved while economic development and expected population growth are accommodated. This report provides sufficient detailed information on which to base future coastal management decisions.

Lamberts Beach.

1 Introduction

Study aim

The favourable climate and the historical pattern of development along the Queensland coast have led to widespread community acceptance of the State's beaches as valuable social assets. The recreational opportunities that beaches provide and their natural attractive appearance have encouraged extensive residential and commercial development of beach areas, often as close as possible to the beach itself.

Aside from their recreational value and their importance as assets to tourism, beaches are an important component of the coast's natural protection. The maintenance of wide sandy beaches and well-vegetated dune systems provides a natural barrier to storm wave energy and protects inland areas against extreme water levels. This feature is of particular importance in low-lying coastal lands that can be prone to flooding.

A detailed knowledge of coastal processes is vital for effective coastal management and planning. This report documents the results of an investigation into coastal processes occurring along the Mackay coast in central Queensland (a regional view is shown in figure 1). An overall view of regional coastal processes is presented, as well as detailed descriptions of individual beaches in the study area. Recommendations on management options for specific issues and individual beaches have been developed, using the available information.

Current issues

Present-day shoreline movements along the Mackay coast are the natural consequences of wind, wave and current forces acting on the beach system. Similar movements have been occurring along this coast for thousands of years. The beaches have remained because natural beach processes tend to maintain a dynamically stable beach form, even where substantial movements occur. In general, it is beneficial to maintain these natural coastal processes so that they can continue unhindered.

Beach erosion is commonly regarded as a problem only when it represents a threat to property and improvements. The cause of the loss of the beaches themselves is often overlooked when the adjacent development is under threat. However, the main issue is not that beaches erode, but that development has occurred within the zone of natural beach movements. In many instances, attempts to protect development from wave attack result in degradation of the adjacent beaches, and achieve only limited success in property protection, the original purpose. Thus, the problems associated with deterioration of recreational beaches and erosion threat to development are related.

At present, a large proportion of the beaches in the study area can accommodate shoreline changes due to beach erosion without detracting from the quality of the beach. However, in some areas erosion has threatened development, necessitating property protection works that have resulted in the loss of the adjacent beach as a recreational asset. While very few private properties are under threat, increasing development pressures may create undesirable situations unless adequate planning and management considerations are incorporated into future development proposals.

The continued existence of beaches in a form in which their aesthetic and recreational potential can be fully realised is threatened in areas where artificial restraints have been imposed on natural beach behaviour. As a result of such interference, costly remedial action is often necessary to prevent complete loss of the beach and to protect existing development from the threat of erosion.

Remedial action can range from expensive major works to relatively cheap management programs, depending on the nature of the problem. Identification of the most appropriate remedial action is not simple and must be based on an accurate explanation of the cause of the problem. The financial resources available to local authorities for beach protection works are generally limited, increasing the need for such funds to be used efficiently. The consequences of incorrect decisions in beach protection matters can be financially severe and physically disastrous for the beach, thus beach protection proposals need to be based on a thorough knowledge of local beach behaviour.

The commercial extraction of sand for reclamation of coastal lands and as raw material for the construction industry has been undertaken for many years in the Mackay region. Sand extraction has been focused primarily around the Pioneer River and the adjacent beaches. The demand for continued access to these resources is expected to continue.

The coastal issues that require specific consideration in the Mackay region include:

- natural, episodic beach erosion caused by storm events;
- fluctuations in the characteristics of tidal inlets, particularly near the Pioneer River entrance;
- the risk of storm tide inundation;
- the sustainable use of sand and gravel resources;
- effects of the Mackay Outer Harbour walls on adjacent coastal processes; and
- vulnerability of coastal areas to sea-level rise and climate change.

Study background

This study of coastal behaviour in the Mackay region has been completed in accordance with section 34 of the *Beach Protection Act 1968*, which includes:

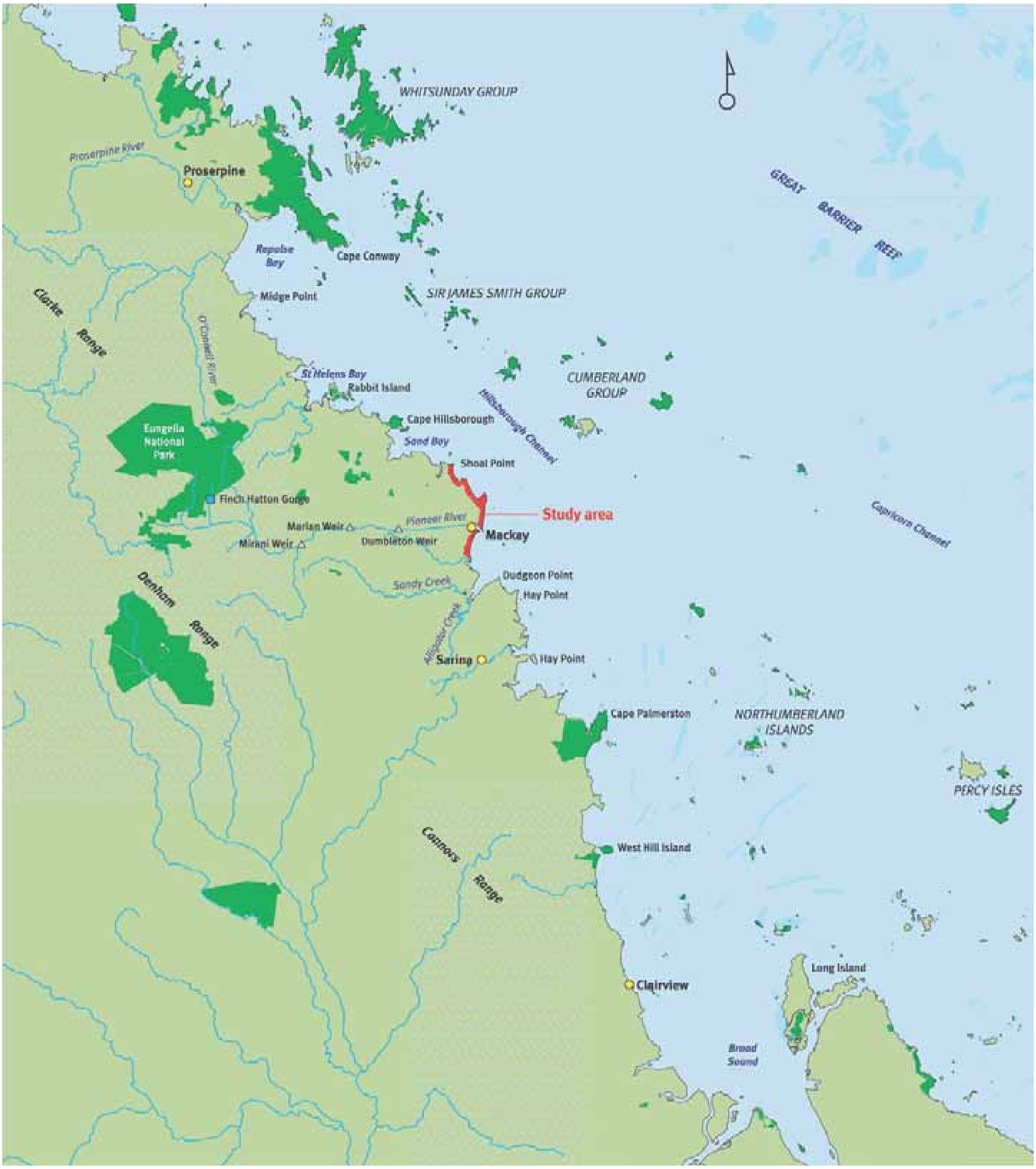
a) the giving of advice and making of reports with respect to coastal management to the Minister, State Government departments, the Marine Board, local authorities, river improvement trusts and other persons; and

b) the carrying out of investigations, conducting of experiments and giving of demonstrations with respect to coastal management.

In order to complete the study, the following data was required:

- physical description of beaches and hinterland;
- historical record of coastal development and coastal changes;
- photogrammetry of recent and historical aerial photography of the area;
- water levels and currents;
- meteorological conditions;
- waves;
- soils;
- vegetation;
- geology; and
- beach profile surveys.

Figure 1 Regional setting



In general, the methods used to assess the data were based on accepted theoretical and empirical procedures. Due to the complexity of the Mackay coastal environment, in particular the large tidal range, many of the procedures were not readily applicable. Emphasis was therefore placed on data actually measured in the field, and calculated results were verified against this before an assessment of beach processes was made.

2 The study area

Introduction

The Mackay Coast study area is limited to about 40km of predominantly sandy coastline extending from Bakers Creek in the south to Shoal Point in the north (figure 2). It contains diverse natural physical features including:

- extensive tidal flats;
- estuaries and wetlands;
- sandy beaches, dune systems and rocky headlands; and
- rocky islands and shoals.

Features such as rocky headlands, estuaries and rivers separate the coast into segmented but not necessarily isolated units. Behind the coastal barrier are substantial areas of marginal lowland. These typically contain mangroves and marshland habitat that are important to marine and terrestrial fauna.

The study area lies fully within the Mackay City Council administrative boundary. Mackay City is the result of an amalgamation in 1994 of the old Pioneer Shire Council and the then smaller Mackay City Council. The local government is now responsible for an area of about 3000km^2 extending from Alligator Creek in the south to the O'Connell River in the north. The Mackay Port Authority is responsible for approximately 200km^2 of this area.

Regional setting

The Mackay region is centred around latitude 21°10' south; the Great Barrier Reef and a number of islands lie offshore. The region is backed by the Clarke and Connor Ranges, which encompass the well-known Eungella National Park and Finch Hatton Gorge.

The Mackay district falls within the Central Queensland Coast bioregion (Sattler and Williams 1999). The area is generally warm, wet and humid, although it can become very dry in winter and spring. The region is subject to occasional severe cyclones that can cause widespread damage from high winds, coastal flooding and severe waves.

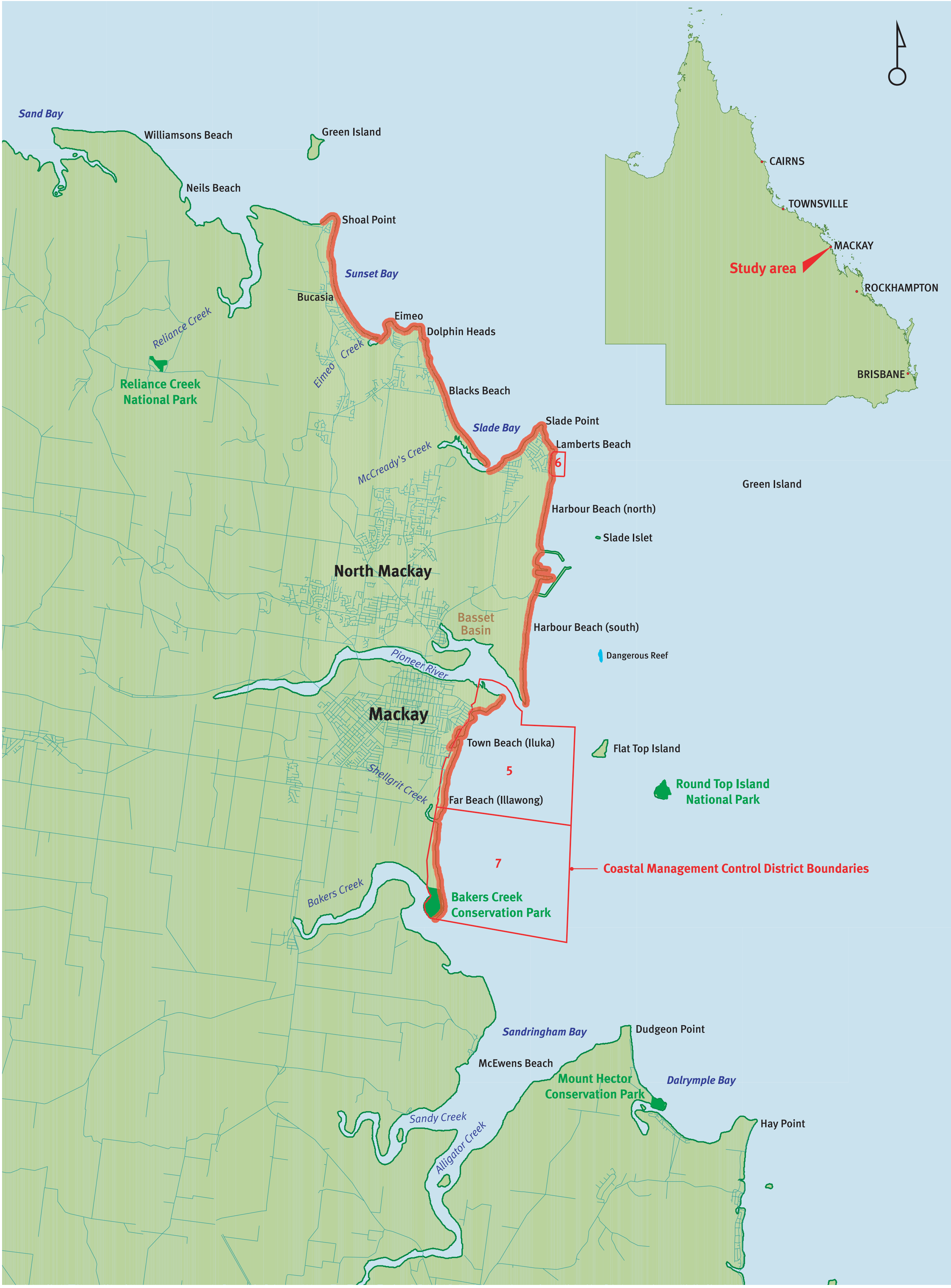
Much of the native vegetation has been replaced by agriculture and some urban development, especially in the lowland areas. A large proportion of the Mackay region supports a prolific sugar industry. Sugarcane was introduced to the area in 1865 and the first mill opened two years later. Since then, the Pioneer valley has become one of Queensland's major sugar-producing areas, producing 1.61 million tonnes of refined and raw sugar in 1997 resulting in gross revenue of $532 million. The region's production covers an area of about 117,000ha, and represents about one-third of the Queensland total.

Beef production in the upper parts of the Pioneer River catchment occupies about 50,000ha and has an estimated value of $4 million. Forestry is also an important industry in the Mackay region.

Urban land has historically been limited. Urban expansion now poses pressure, especially in coastal areas that are currently used for agriculture.

Dolphin Heads and Blacks Beach in the background.

Figure 2 Locality plan



Mackay City Council has recognised this pressure and its strategy for urban development is directed at preserving arable land on a priority basis.

The Pioneer River is the predominant catchment in the region; its area is 1,489km^2. The catchment is relatively small compared with the Fitzroy River, located further south, with a catchment area of 142,645km^2. The average annual flows for the Pioneer and Fitzroy Rivers are 900 million m^3 and 6,000 million m^3 respectively.

The City of Mackay, with a population of 62,548 in 1998, is the major service centre in the region. It serves the coal mining infrastructure in the Bowen Basin to the west, as well as providing services to the agricultural industry and port-related facilities.

Main geographical features

The major feature on the coast is the Pioneer River, which divides Mackay into two areas of development. Weirs have been built at Dumbleton, Marian and Mirani. The river is tidal up to Dumbleton Weir, 16.5km from the river mouth. In times of flood the Pioneer River can be expected to deliver large quantities of water and sediment to the coast. Training walls to improve navigation and for bank protection have altered the natural river bank of the lower estuary.

The other significant catchment in the study area is Bakers Creek, a previous course of the Pioneer River in relatively recent geological times. Shellgrit, McCreadys and Eimeo Creeks are other smaller watercourses flowing directly into the Pacific Ocean.

To the east and south of the Pioneer River are Town and Far Beaches, which feature extensive tidal flats. These intertidal areas, more than three km wide in places, form part of a large nearshore sediment deposit extending into Sandringham Bay. Much of the coastal area south of the river has been significantly altered by development activities over the past 50 years.

To the north of the Pioneer River entrance is Harbour Beach, with Slade Point and Lamberts Beach at its northern extremity. Near the centre of this section is the Mackay Outer Harbour, with associated industrial areas and the recent small boat marina development. Harbour Beach is the home of the Mackay Surf Lifesaving Club and has a patrolled swimming beach.

Further north is Blacks Beach, the longest continuous stretch of beach in the Mackay area. Named after M.H. Black, the local Member of State Parliament in the 1880s and 1890s, it has been a popular holiday destination for the local community since the 1870s. Major tourist development started in the 1970s, with holiday apartments, units, resorts and caravan parks being built along the shore.

Dolphin Heads, named for the resemblance of the headlands to the heads of two dolphins, is at the northern end of Blacks Beach. It has a few private residences and a beachfront resort. Eimeo, to the west of the headland and overlooking Sunset Bay, has a number of holiday units and a popular cliff-top hotel.

The northernmost beach in the study area is at Bucasia. Originally named Seaview, the township of Bucasia was renamed after Father Pierre Bucas, who ran an orphanage in Mackay from the early 1870s. It became a popular beach and the Pioneer Shire Council built conveniences and a bathing shed in 1923 to serve up to 200 people who camped there during holiday periods. More recently, resorts, caravan parks and holiday units have been built along the beachfront.

Pioneer River showing Cullen Island in the foreground.

Historical overview

For thousands of years the coastal district was inhabited by the Yuwi community. The Yuwi lands stretch from Rabbit Island in the north to Cape Palmerston in the south. The Yuwi people relied on coastal resources and were noted fish and shellfish eaters. Fish traps can still be seen in Sand Bay just north of the study area.

The Mackay coast was surveyed in 1819 by Lieutenant Philip King, and was first settled by Europeans in the early 1860s after the separation of Queensland from New South Wales in 1859. John Mackay arrived in 1860, in the company of seven other men, looking for new pastures for cattle. He was soon followed by other settlers. The settlement of Mackay was founded in 1862 and was declared a town in 1866. It has remained the service centre for the region despite considerable difficulties in the provision of an adequate port for many years.

In 1862 the government ship *Pioneer*, under the command of Commodore Burnett, surveyed the Pioneer River for a harbour. Agriculture was centred around cattle and sheep farming before sugar production began in 1865.

Mackay, six km from the river entrance, became an official port in 1863. From the beginning, the depth of water and strong currents in the river posed a problem for navigation. Wharves and associated port infrastructure were built along the south bank of the river to handle small vessels. Larger vessels however, had to anchor at high water in the lee of Flat Top Island, 4.5km south-east of the entrance, to transfer both cargo and passengers by lighter.

Over the next 75 years continual efforts were made to improve shipping conditions within the river by dredging and construction of rock training walls. Many schemes to connect the mainland to a proposed new port area at Flat Top Island were developed but did not eventuate, mainly because of the high cost of construction. Some benefit was gained when the river broke through the northern bank at the entrance during a cyclone in 1898, forming an improved channel. However, the improvement was short-lived and eventually a decision was made to construct a new port on the coast north of the river entrance.

Work began on the new harbour in 1935 and the port was officially opened on 26 August, 1939 by the Premier, the Hon. W. Forgan-Smith. It was connected to Mackay and the hinterland by both road and rail. The number of vessels currently using the port is still lower than the number that visited the river port in 1926. However, the tonnage of cargo through the port has increased from about 110,000 tonnes in 1926 to more than 2.5 million tonnes in 1997 to 98.

The Pioneer Shire Council was formed in 1902, replacing the previous Divisional Board. The Council initially had powers in the areas of railway building, town planning, health, public halls and agricultural drainage. The City of Mackay was declared in 1918, and in 1994 the adjacent Pioneer Shire Council was absorbed into Mackay City Council.

Mackay Harbour in 1997 prior to construction of the small boat harbour.

3 Coastal land use

Introduction

Steady growth has been observed in the Mackay region since settlement, coupled with intermittephases of rapid growth and economic upturns in agriculture and farming. This expansion has largely been attributed to the sugar industry, which remains the most important regional industry. Increased sugarcane production resulted in the establishment of additional sugar mills, roads, a port and other services. Industries other than agriculture usually fall into the category of service industries for the rural sector and commerce. More recently, the tourism industry has played an increasingly important role in the regional economy.

Mackay City Council's Strategic Plan (Mackay City Council 1999) shows broad land use designations throughout the study area. Of interest are the following features:

- the extensive areas of coastal lands designated 'Open Space and Recreation';
- a new area of tourism development planned for East Point, south of the harbour;
- planned completion of the reclamation works in East Mackay, which will provide additional residential areas and enable the connection of the road (Binnington Esplanade) between Town Beach and Far Beach; and
- possible expansion of tourism development at the northern end of Town Beach adjacent to the Pioneer River.

Land use types

Residential

Extensive areas of coastal land in the study area are used for residential purposes. A number of residential properties are located adjacent to the shoreline. In some cases, coastal erosion has threatened properties and prompted the construction of rock walls. These have become significant features along a section of Blacks Beach. Additionally, many residential areas are relatively low-lying and are subject to the risk of flooding and storm-tide inundation.

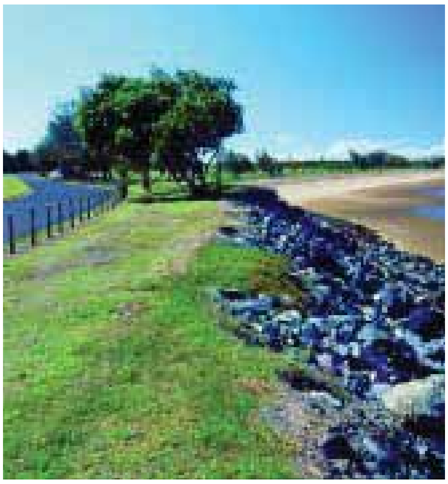
Many residential areas south of the river have been reclaimed using coastal sand resources. At Town Beach reclamation works in 1964 created a deep hole just offshore. The dredged area, which is still visible, resulted in an erosion threat to the esplanade road, necessitating the construction of a rock wall.

A notable operation was carried out in 1985 when the Land Administration Commission removed 280,000m^3 of material from an area 500m offshore to raise the level of a residential area in East Mackay.

The population of the City of Mackay has increased steadily over the past few years (table 1). A large proportion of the population growth has been in the northern Mackay beach suburbs (table 2). The increase in population in the region is expected to continue (table 3 shows the Australian Bureau of Statistics population projections until the year 2011).

Recreation and tourism

The Mackay tourism industry is expanding and has an estimated total annual turnover of $250 million. The coastal areas around Mackay have been visited for recreation and fishing since the late 19th century. Tourism was not significant until the late 1940s, when tours to inland national parks and the Great Barrier Reef islands began. Motels, caravan parks and resort developments at Far Beach and the northern beaches are relatively recent and are competing with residential use for lands along the beachfront.



Binnington Esplanade and protective rock wall at Town Beach.

Statistics for the region show that the number of official guest rooms is increasing at an annual rate of approximately four percent (Mackay Tourism and Development Bureau 1998). A number of developments have been recently completed in the northern beach areas, including significant integrated resort and marina infrastructure at Harbour Beach.

Town Beach and Far Beach are close to the city centre and are popular with both local

Table 1 Estimated resident population statistics by year.

	1987	1992	1997	Annual change 1987 to 1992	Annual change 1992 to 1997
Mackay City	51 597	55 895	62 442	+1.7%	+2.3%
Queensland	2 675 107	3 032 834	3 401 232	+2.7%	+2.4%

Table 2 Breakdown of Mackay population by year.

	1991		1996		Annual growth rate 1991 to 1996	
	Persons	Dwellings	Persons	Dwellings	Persons	Dwellings
Bucasia	2 009	749	2 398	913	3.9%	4.4%
Eimeo	918	330	1 357	524	9.6%	11.8%
Blacks Beach	627	252	820	233	6.2%	−1.5%
Shoal Point	477	178	622	236	6.1%	6.5%
Mackay City	41 012	15 041	44 880	17 298	1.9%	3.0%

Table 3 Estimated resident population statistics by year.

Projection	2006	2011
High	86 030	93 220
Medium	82 810	88 040
Low	80 410	84 260

residents and tourists. Views of Round Top and Flat Top Islands, and the huge expanses of sandflats at low tide are an attraction.

Mackay is a departure point for island resorts and visits to the Great Barrier Reef. A number of cruise boats and charter fishing boats are also based in Mackay. Moorings in the new small craft harbour provide facilities for larger vessels that use the fishing grounds off the coast.

Recreational fishing is a popular pastime throughout the study area. Boat ramps give small boats access to creeks and nearshore fishing areas. Shore-based fishing is common along the area's beaches and headlands.

Commercial

Commercial fishing initially supplied only the local market, but since 1930 the industry has developed substantially. In 1934, 78 licences were issued at Mackay, increasing to 824 in 1948, with 258 fishing boats and a yield of about 160t. By 1956, Mackay's production was about three percent of the total Queensland catch and ten percent of the State's barramundi catch. In 1970/71, 72t of mostly reef fish and 67t of prawns were landed. By 1997/98, the total catch had reduced to 70t.

Although the aquaculture industry is developing throughout the central Queensland coastal region, it has not yet become significant in the study area.

Sand and gravel extraction from the lower reaches of the Pioneer River and coastal areas is a significant commercial activity supporting the local economy. Over the last two decades an average of 100,000m^3 of sand and gravel was removed annually from the lower reaches of the Pioneer River for the construction industry.

Significant quantities of sand are also commercially extracted from Bakers Creek, with an annual limit of 50,000m^3. From 1984 to 1990, permission was given annually to dredge up to 40,000m^3 of sand from the intertidal area north of the entrance of Bakers Creek. However, the actual quantity reported as having been removed was below this limit. The section of Harbour Beach south of the harbour has provided a regular source of sand, with annual average extraction rates of the order of 40,000m^3 over many years.

A number of reclamation works using coastal sediments have been completed as part of the city's development. In 1978 about 620,000m^3 of material was dredged from the Pioneer River near Mackay city centre (Cullen Island) to reclaim the Caneland Shopping Centre site near the city centre. Extensive areas south of the Pioneer River have also been reclaimed, mainly for residential development.

Weirs have been constructed on the Pioneer River at Dumbleton, Marian and Mirani to provide water for agriculture and for urban supplies. These weirs have significantly altered the characteristics of the river and their effects are noticeable for many kilometres upstream.

Port of Mackay

The Port of Mackay is an important part of the local economy, providing a valuable service for the export of sugar and grain, and the import of petroleum, fertiliser and magnetite. The Mackay Port Authority also manages the local airport.

The construction of the harbour between 1935 and 1939 was successful in establishing a port with largely all-weather and all-tide access to most commercial shipping, thus overcoming navigation problems in the river entrance. Relatively minor maintenance dredging is required to remove fine sediments that become trapped in the low-energy conditions created by the harbour walls. As there are no significant freshwater inflows to the harbour, the major source of fine sediments is from the exchange of water with the nearshore tidal flows. Most of the material dredged from the harbour to maintain required depths is placed in a disposal area approximately four km offshore from Slade Point.

Previously, capital dredging works have been completed to deepen various sections of the harbour. The dredged material was mainly sand and was typically pumped over the north wall of the harbour into the littoral zone.

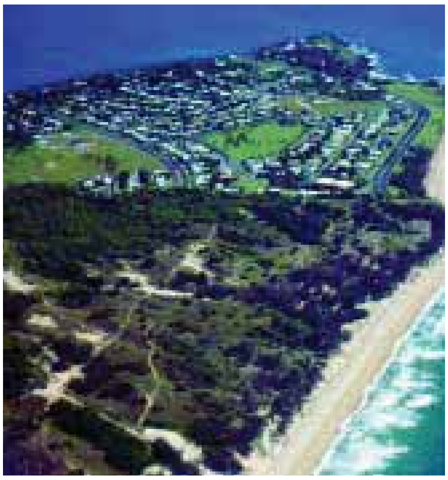
Reserves

The only national park within the study area is the Reliance Creek National Park (14ha), located seven km west of Bucasia. The study area has two conservation parks. One (46ha) is located on the northern bank at the entrance to Bakers Creek and is a recurving spit with mangrove stands providing an important marine habitat and a nesting site for birds. The other is a geological formation at Mount Hector.

A special conservation reserve at the northern end of Harbour Beach, known as the Slade Point Reserve, is managed jointly by the Mackay City Council, the Department of Natural Resources, Mines and Energy and the Environmental Protection Agency. This area is especially important as it is representative of the natural vegetation patterns of the Mackay region. The Australian Heritage Commission has placed the area on the Interim List of the Register of the National Estate. The area was nominated because it has been identified as containing regionally significant vegetation and fauna communities. South of the Slade Point Reserve is a similar area maintained (for conservation purposes) by the Mackay Port Authority. Together, these areas comprise an important tract of remnant wetland and dune system close to the urban and industrial development of northern Mackay.

'Important Wetlands' form the northern and southern boundaries of the study area (Commonwealth of Australia 1996). These are Sandringham Bay/Bakers Creek to the south, and the Sand Bay Wetlands north of Shoal Point. The Sandringham Bay/Bakers Creek aggregation consists of freehold, leasehold and vacant Crown land. Sand Bay is a Fish Habitat Area (Management A) and is partly State Marine Park, with the remainder consisting of freehold and leasehold land. Both areas are significant because they are examples of marine and estuarine wetlands of the Central Queensland Coast bioregion. They have extensive expanses of intertidal mudflats backed by mangrove forest, and are particularly important as fish and shorebird habitat.

Bassett Basin in the estuary of the Pioneer River was declared a Fish Habitat Area (Management B) in 1993. It was previously a wetland reserve and is managed to enhance existing and future fishing activities by protecting fish habitat. The area consists of substantial mangrove forest and tidal creeks that are fish nurseries.



Slade Point Reserve.

4 Geology

Most studies of the coastal geology of the Mackay region are based upon the Bureau of Mineral Resources regional study (Jensen et al. 1966). Three studies were commissioned by the Beach Protection Authority:

1. The Geological Survey of Queensland undertook a seismic profiling survey in the region from the Hillsborough Channel in the north to Hay Point in the south, including interpretations of the shallow seismic stratigraphy in the area (Hegarty 1983).
2. In 1986, the Geological Survey of Queensland (Jones 1987) reported on the distribution of the nearshore sediments near Mackay, including an examination of more than 300 sediment samples collected during March and April 1986. The report describes the distribution of sediments along the Mackay coast, infers directions of sediment transport, and investigates possible transport mechanisms.
3. The Water Resources Section of the Department of Natural Resources (formerly in the Department of Primary Industries) studied terrestrial geology (DPI 1995). The report contains detailed descriptions of geomorphology, stratigraphy, age structure, depositional processes and a discussion of evolutionary models.

The coastal geology of the study area is summarised in figure 3. The surface geology of the coastal region is dominated by two groups:

- the primarily Palaeozoic (in the order of 200 million years in age) volcanic and sedimentary bedrock outcrops of the Campwyn Beds. Examples of these outcrops include the prominent headlands, Slade Point, Dolphin Heads and Shoal Point; and
- the relatively recent Holocene (up to 10,000 years in age) deposition of coastal sediments comprising the extensive system of sandy beaches formed through the region.

These two groups make up the majority of the coastal features in the Mackay region. Pleistocene age (2 million to 10,000 years before present [BP]) sedimentary deposits occur extensively through the terrestrial part of the area, although the coastal exposures are relatively limited. Exposures of these stiff clays can be seen in the mouths of Bakers and Shellgrit Creeks.

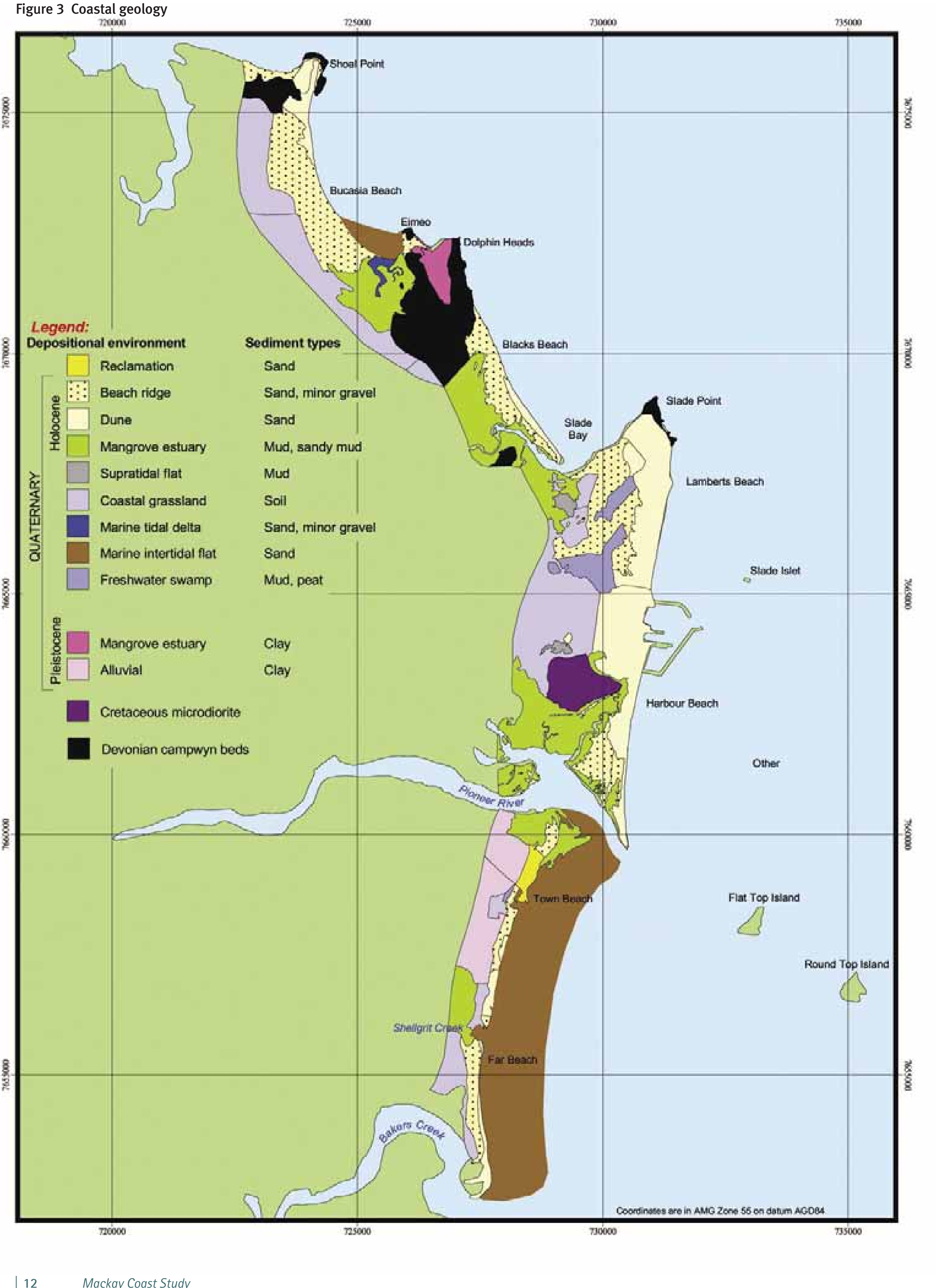
Pleistocene sediments are generally composed of silty clay to clayey sand and sometimes contain calcareous nodules. Colours range from mottled orange-brown to grey-green. Some areas of unconsolidated Pleistocene sediments are also found; these include relict beach ridges north of the Pioneer River. Part of the active nearshore zone also includes sediments derived from the Pleistocene period.

Analysis of records from a number of drilling programs has enabled an estimate to be made of the approximate underlying Pleistocene surface near the coast. From this, a representation of the historical shoreline prior to the most recent phase of Holocene deposition was derived and preliminary estimates of a sediment budget made (DPI 1995).

Discussions of the geological history and the present-day coastal sedimentation regimes are provided in later chapters.

The entrance Bakers Creek.

Figure 3 Coastal geology



5 Soils

Introduction

The Queensland Department of Natural Resources surveyed and mapped the soils of the Mackay coast on behalf of the Beach Protection Authority. Figure 4 provides a summary of the findings.

Landscape units are defined as areas of topographic and geomorphic similarity. Soil types are defined as a group of soil profiles that can be grouped according to the similarity of their morphological characteristics, and their occurrence is coherent enough to be represented on a map. The study area has been divided into four major landscape units containing ten soil types (table 4).

Table 4 Landscape units and soil types of Mackay

Landscape unit	Soil types
Quaternary beach ridges	Andergrove Andergrove watertable variant Andergrove calcareous variant
Estuaries, swamps and flood plains	Dundula Mangroves Saline flats Swamps
Relict levees	Cameron Pioneer red B horizon variant
Rises and hills on Andesite	Habana

Landscape units

Quaternary beach ridges

Quaternary beach ridges are comprised predominantly of siliceous sand dunes of varying heights. Up to four sets of dunes extend from the frontal dune. The dunes often overlie the watertable at the margins of estuaries, swamps or flood plains and have buried mangroves and saline flats.

Andergrove soils are poorly sorted siliceous sands. They consist of littoral and aeolian deposits of coarse-textured yellowish-brown sands. Coarse sands dominate, with a coarse to fine sand ratio usually greater than 1:4. This ratio is at a maximum in the hind dunes and at a minimum in the frontal dunes. Nutrient levels and water-holding capacity are extremely low in all Andergrove soils. Most of the urban development within the survey area has occurred on this soil type.

The watertables associated with the Andergrove watertable variant soil unit near the airport and at Shoal Point have extremely low pH levels (less than 3.0) therefore, the acid sulfate potential of these areas is very high. Watertables from the other areas ranged in pH from 4.0 to 8.8, which may be related to the presence of calcareous sand sediments.

Small areas of calcareous sands are also found on either side of the mouth of the Pioneer River. These sands have high pH levels (greater than 8.0 at depth), and often have small rounded pieces of pumice on the surface and shell grit in the soil profile.

Estuaries, swamps and flood plains

This landscape unit comprises mangroves adjacent to creeks, freshwater swamps, and supratidal and intertidal flats. Cracking clay areas appear to have buried former areas of saline flats. All soils in this landscape unit generally have high to extreme acid-sulfate potential.

Dundula soils are dark-grey cracking clay soils found in low-lying areas adjacent to mangroves. The soil is characterised by its relatively high clay content (35 to 40 percent). Because of the clay content and its landscape position, the soil is subject to frequent wet-season waterlogging and in some years may not dry sufficiently to exhibit surface cracking.

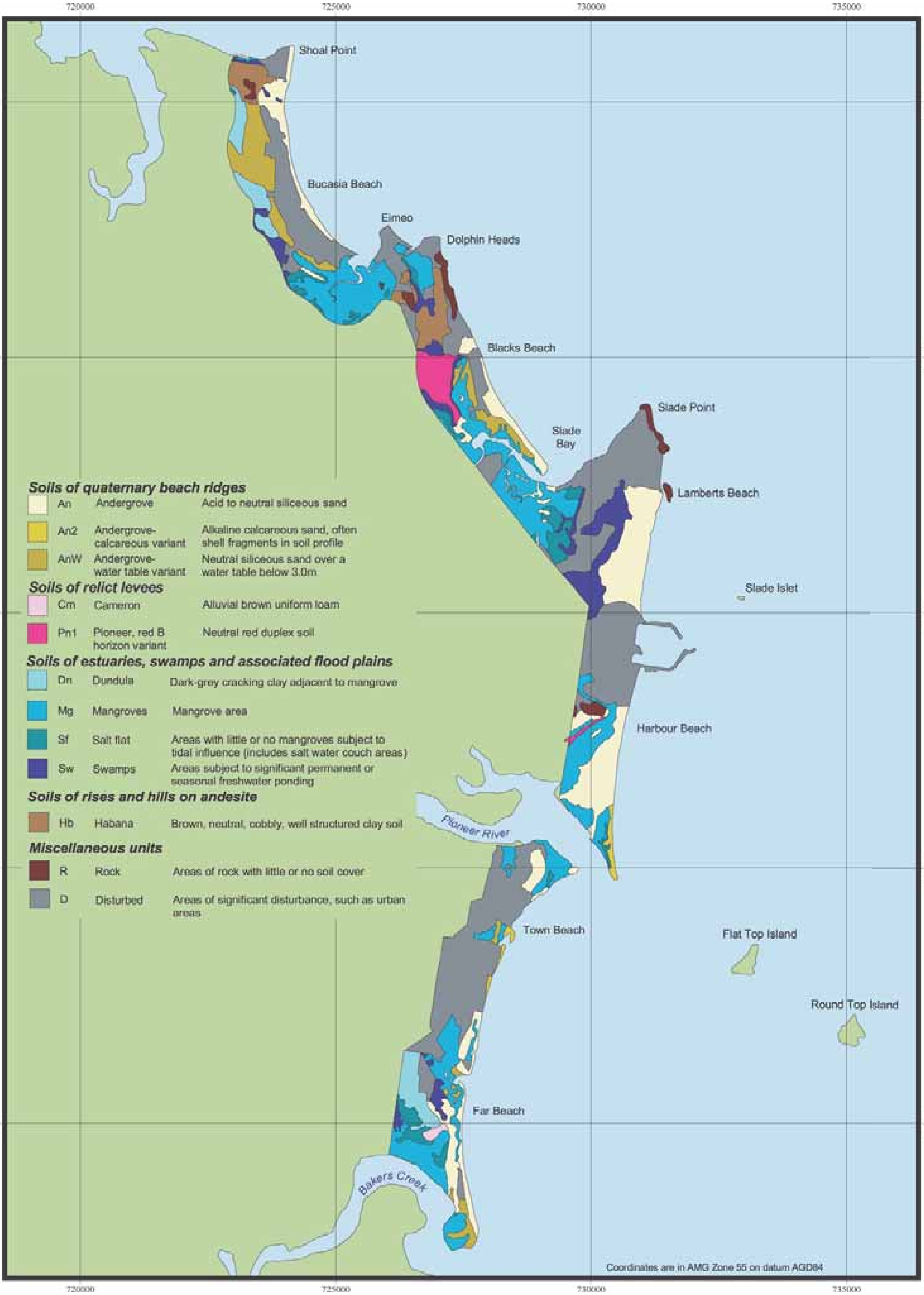
Fertility is moderate to high throughout the profile. The pH is acid to neutral, although this soil exhibits a very strong acid-sulfate potential and high salinity at depth.

Saline flats and mangrove soils are high in fertility, clay content, chloride and salinity levels. The pH is neutral on the surface, decreasing to a very low level (3.5 at and below 1.5m soil depth), indicating a very high acid-sulfate potential. Saline flats tend to be inundated only on large tides.

Swamp areas are subject to significant permanent or seasonal freshwater ponding, generally adjacent to hind dunes. The largest occurrence is in the Slade Point area.

These soils are loamy, being dominated 100:1 by fine sand rather than coarse sand, although coarseness increases with depth. Fertility is moderate and decreases with depth. The pH is moderately acid (5.7 to 6.3) and decreases significantly with depth. The low pH values may indicate a high acid-sulfate potential.

Figure 4 Soil types



Relict levees

Relict levee areas located away from the present coastline are often two to three metres higher than the surrounding mangrove or dune areas, and have very contrasting soils and vegetation. A small relict levee occurs just south of Mount Bassett.

The Cameron soil type is an alluvial brown uniform loam located on a slightly elevated ridge south of Mackay Airport. This soil area has mostly been cleared and cultivated for sugarcane.

Loam textures are dominant in the subsoil, although the surface is often sandy and a sandy buried layer is evident below 1.5m soil depth. The coarse to fine sand ratio is low, being less than 0.5 in the subsoil. Fertility levels are low and the pH is moderate (5.5 to 6.5). A very low pH (3.2) is evident in the buried sandy layer, this reflects the acid-sulfate potential of this layer.

The Pioneer red B horizon variant is a neutral red duplex soil. It occurs on pronounced ridges above surrounding Andergrove soils and mangrove or freshwater swamp areas. This soil has a sandy topsoil directly overlying a red clay subsoil. The depth of topsoil varies from 25 to 35cm. Fertility levels appear to be good. Most of these areas have been cleared and cultivated to grow sugarcane or tree crops such as mangoes. The pH is neutral and salinity levels are very low.

Rises and hills on Andesite

A well-structured brown clay is associated with the low rises and hills on Andesite or similar volcanic rocks. This soil has varying depth to rock and a varying cobble amount within the soil profile. Rock areas are defined as areas of outcrop with little or no soil. They occur north of the river at Mount Bassett, Slade Point, Dolphin Heads, Eimeo and Shoal Point.

Habana is a brown well-structured clay soil with a maximum soil depth to rock of about 0.6m. Slopes of the land vary from two percent in the less sloping areas to greater than 30 percent in the steeper areas.

Habana soil is a uniform clay soil (30 to 40 percent clay) or a gradational soil with a clay loam topsoil (25 to 30 percent clay) with a gradually increasing clay content with depth. The subsoil colours range from brown to reddish-brown. The profile is well-structured throughout, with general fertility moderate to high. The pH is generally neutral and salinity is low.

Areas such as Mount Bassett where there is abundant rock and little or no soil have been mapped as rock. Areas of Habana with deeper soil and less surface rock have been used for sugarcane cultivation, although most of these areas have now been developed for urban purposes and have been mapped as disturbed in this survey.

Stability of slopes under urban development is a major concern within the survey area; in particular the risk of mass movement (landslides) in the steeper areas.

Bedrock outcropping Harbour Beach north.

Acid sulfate potential

A major acid-sulfate potential exists in many survey areas due to the history of formation of some of the soils and landscapes. All areas of existing estuaries, swamps and associated flood plains generally have high to extreme acid-sulfate potential.

Areas that have been buried by more recent deposits, such as in the Bakers Creek area and at Shoal Point (west of the Mackay–Bucasia road) also have high acid-sulfate potential.

The relict levees, rises and hills on Andesite and most of the sand dune areas appear to have little or no acid sulfate potential. The exception is the Andergrove watertable variant soil type. Analysis of the watertable indicates that it has very low existing pH and high acid-sulfate potential at specific locations.

6 Vegetation

Introduction

Beach Protection Authority commissioned the Queensland Herbarium to undertake a vegetation and floristic survey of the Mackay coast, extending south to Hay Point (Batianoff and Franks 1997). A detailed vegetation survey of the area immediately north of Mackay Harbour was conducted for the Mackay Port Authority. Sattler and Williams (1999) also detail the regional ecosystems of the area.

The study area is dominated by rural land (48 percent) and urban land (13 percent). Land with remnant native vegetation covers about 33 percent of the study area. The remnant native vegetation is comprised of wetlands (80 percent) and terrestrial vegetation (20 percent).

A total of 1,123 species of plants have been recorded. Of these, 800 (71 percent) are native, 310 (28 percent) are exotic, and 13 (one percent) are Australian plants not indigenous to the Mackay area. Eleven vegetation associations have been mapped in the study area (figure 5 and table 5).

Vegetation associations

Saline flats

Saline flats are the most extensive vegetation association found in the study area. They include areas of mangroves and intertidal herblands. Extensive tracts occur around Reliance Creek, Slade Bay, Bassett Basin, Bakers Creek and Sandringham Bay.

Mangroves cover 19 percent of the study area and 74 percent of all intertidal vegetation areas. Twenty-one mangrove species were recorded, representing just over half of the 38 known Australian species. The mangrove structural formations of Mackay vary from closed forests to low scrublands, with two to eight metre high closed scrubs being most common. Many communities consist of monospecific stands of *Ceriops tagal*, *Rhizophora stylosa* and *Avicennia marina*.

Intertidal herblands cover the remaining intertidal vegetation areas. Intertidal herblands are comprised of saltmarsh and saltpan vegetation. These areas occur on the landward edge of the intertidal zone. The soils are often hypersaline due to evaporation and infrequent tidal inundations. The intertidal herblands vary from open herbland to closed grassland. They are usually dominated by *Sporobolus virginicus*.

Sandy seashore, strand and littoral vegetation

Sandy seashore vegetation is found on dunes along exposed and sheltered beaches. Mackay's sandy seashore vegetation consists of 227 species, 40 percent of which are introduced. Beach strandline herblands occur on high-energy sandy coasts on mobile foredune areas.

Table 5 Description of the vegetation associations found in Mackay

Vegetation association	Sub-units and description
Saline flats	a) Mangroves – vary from closed forests to low scrublands; 21 species recorded; communities vary from monotypic to mixed stands.
	b) Intertidal herblands – vary from open herbland to closed grassland; *Sporobolus virginicus* is widespread.
Sandy seashore	Strandline – foredunes colonised by *Spinifex sericeus* open grassland, landward of which is an *Ipomoea pes-caprae* zone.
	Casuarina woodland – dominated by *Casurina equisetifolia* var. *incana.*
	Casuarina woodland with beachscrub – dominated by *C. equisetifolia* var. *incana* with rainforest species scattered throughout.
Freshwater swamp with treeless herbland	Freshwater wetland areas of swamp grasslands, swamp sedgelands and open water herblands.
Freshwater swamps with melaleuca	*Melaleuca leucadendra* open forest – dominated by *M. leucadendra* often forming monospecificstands and found in low-lying areas.
	Melaleuca dealbata open forest – dominated by *M. dealbata* with the occasional eucalypt species such as *E. platyphylla* and *E. tereticornis* growing on coastal beach ridges. These areas are drier than the areas where *M. leucadendra* dominate.
	Melaleuca viridiflora open forest – dominated by *M. viridiflora.* Often with eucalypt emergents. Found on wet dune sandy soil. Regrowth areas characterised by monospecific stands of *M. viridiflora.*
Riparian forest	Estuary riparian forest – occurs on lower reaches of tidal waterways. Intertidal margins support mangrove low closed forest dominated by *Rhizophora stylosa* and *Avicennia marina* and landward areas support eucalypt/melaleuca open forest.
	Tidal mid-reach riparian forest – narrow band of mangroves usually dominated by *Aegiceras corniculatum* with adjoining eucalypt open forest.
	Freshwater mid-reach riparian forest – occurs on levee banks. Includes wetland vegetation and gallery forests.
	Freshwater upper-reaches riparian forest – consists of mixed gallery open forest dominated by *Casuarina cunninghamiana* subsp. *cunninghamiana.*
Lowland littoral rainforest	Emergent sparse canopy dominated by *Terminalia sericocarpa.* Includes mid-dense tree canopy, an understorey of tall shrubs and sparse groundcover.
Hill and headland rainforest	Range from simple to complex notophyll vine forests.
Eucalypt open forest including a number of different forest types	*Corymbia tessellaris* open forest.
	Eucalyptus crebra open forest.
	Mixed eucalypt open forest.
Beach scrub	Patches of rapidly growing rainforest species growing on sandy seashore areas.
Rocky shore vegetation	Closed grassland and closed herbland that grow on rocky shores.
Disturbed	Vegetation cleared for cultivation or development.

Figure 5 Vegetation associations

These unstable beachfront areas are colonised by Spinifex sericeus open grassland. S. sericeus open grassland occurs as a continuous zone along Harbour Beach, Shoal Point to Blacks Beach and Far Beach.

A second band of strand herbland is found landward of the *S. sericeus* open grassland. It usually includes *Ipomoea pes-caprae* subsp. *brasiliensis*. In sheltered areas and along low-energy sandy coasts, strand herbland is more prominent and replaces *S. sericeus* open grassland. The strand herbland is also present between mangroves and terrestrial forested vegetation.

Beach ridge and dune casuarina low woodland and open forest is the most dominant woody vegetation landward of strand herbland. The dominant species is *Casuarina equisetifolia* var. *incana*. It forms low woodlands and open forests seven to twelve metres high. Large areas of *C. equisetifo*lia var. *incana*, as seen between Slade Point and East Point, may indicate recent coastal accretion and/or dune disturbances. Beach ridge and dune casuarina vegetation with beach scrub elements is usually found behind both exposed and protected beaches. However, north of East Point, a large area of *C. equisetifolia* var. *incana* open forest occurs with beach scrub elements.

Freshwater swamp with treeless herbland

Aquatic treeless herblands include swamp grasslands, swamp sedgelands and open water herblands. A total of 104 plant species, including 85 native species (82 percent), were recorded from treeless freshwater wetlands. The flora includes emergent grasses, rushes and sedges frequently found in shallow water and/or wetland edges. The deeper and open water areas support many floating submergent aquatic plants.

Freshwater swamp with melaleuca open forest and woodland

The melaleuca open forests and woodlands of the Mackay Coast are among the more significant native wetland vegetation types found within the study area. These wetland forests support 193 native (63 percent) and 113 introduced (37 percent) vascular plants.

Melaleuca leucadendra open forests are particularly important and are found in low-lying coastal areas at Slade Point, Far Beach and McEwens Beach (locally known as McEwans Beach). *M. leucadendra* dominates this forest type, forming a mid-dense canopy 18–30m tall, often as monospecific stands. The secondary canopy and shrub layer is poorly developed and groundcover is sparse.

Mangroves in McReady's Creek

Melaleuca dealbata open forests occur on coastal beach ridges of low relief on sandy soils at Shoal Point and Dunrock, and near Dudgeon Point. These sites are considerably drier than those found with *M. leucadendra* open forest. The canopy is mid-dense, 15 to 25m high, and dominated by *M. dealbata* with occasional eucalypt species such as *Eucalyptus platyphylla*, *E. tereticornis* and *Corymbia tessellaris* growing on the raised beach ridges. The lower canopy is sparse, four to twelve metres tall, and comprised mainly of littoral rainforest species. The shrub to small tree layer and groundcover are sparse.

Melaleuca viridiflora low woodland to low open forest occurs as natural formations or as regrowth after clearing. The disturbed communities are easily identified by monospecific stands of *M. viridiflora*.

Small areas of *M. viridiflora* low woodland occur on wet dune sandy soils near Slade Point. Larger areas of *M. viridiflora* open forest with emergent eucalypts occur on more fertile coastal plains soil such as those found near Slade Point and near Mount Hector.

Riparian forest

Riparian forests occur along the majority of the creeks in the study area as well as along the Pioneer River. Specialist riparian plant species also occur, such as *Casuarina cunninghamiana* subsp. *cunninghamiana*. Some mangrove species are included as riparian as they provide a transitional zone between tidal marine channels and dryland vegetation.

Riparian forests are the second most diverse assemblage in the study area, with 309 (71 percent) native and 127 (29 percent) introduced species. The high species richness of riparian forests results from the combination of aquatic, wetland, dryland, rainforest and open forest species growing within one ecosystem.

Estuary riparian forests occur on the lower reaches of tidal waterways. The intertidal margins support mangrove low closed forest four to twelve metres tall. The low estuary banks are typically sandy beach ridges and/or a coastal plain consisting of a mixture of alluvium sand and gravel. Melaleuca/eucalypt open forest up to 18m tall occurs landward of the mangroves.

Tidal mid-reaches riparian forest occurs in most creeks within the study area because the tidal range is large. The tidal limits vary, extending between two and eight km inland from estuarine areas. A narrow mangrove fringe occurs in the middle reaches. Adjoining this zone are eucalypt open forests up to 25m tall.

Freshwater mid-reach riparian forest occurs on levee banks at Reliance, Bakers and Louisa Creeks. The zonation pattern includes a wetland vegetation zone, a gallery rainforest zone and a eucalypt open forest zone.

Much of the freshwater upper-reach riparian forest vegetation type occurs inland, outside the 5km wide coastal study strip. It includes mixed-gallery open forest in creek beds and lower-terrace slopes and eucalypt open forest on upper-terrace slopes.

Lowland littoral rainforest

Most of the lowland littoral rainforests that occur on fertile alluvial soil in the Mackay region have been cleared for sugarcane cultivation. Two small areas of lowland littoral rainforest remain along the middle reaches of Reliance Creek and the upper middle reaches of Louisa Creek (near Timberlands). These areas have a large number of native species (226) and are relatively weed-free.

Hill and headland rainforest

Hill and headland rainforest occurs as small, isolated fragments on slopes or on well-developed headland soils. Rainforest patches occur on Mount Bassett, on hills near the Blacks Beach area, and on headlands at Dolphin Heads and Eimeo. Despite the small size, hillside and headland rainforest has a high native diversity (209 species) and a very low proportion of introduced species (seven).

Hill, headland, lowland and dune eucalypt open forest

Eucalypt open forests are found on a variety of soils and topography along the Mackay Coast, from dune systems and well-developed alluvial soils to rocky substrates. The eucalypt open forest complex of the Mackay coast is the most diverse native vegetation type found within the study area. It supports 356 (70 percent) native and 152 (30 percent) introduced vascular plants.

Eucalypt open forests dominated by *Corymbia tessellaris* are most often found in sandy soils of alluvial plains and beach ridge systems landward of coastal *Casuarina equisetifolia* var. *incana*.

C. tessellaris open forest with beach scrub understorey is closely associated with coastal areas and sandy substrates, usually found landward of the casuarina woodland zone at Bucasia, Shoal Point, Blacks Beach, Slade Point, Andergrove, Far Beach and Bakers Creek.

Open forest characterised by the predominance of *Eucalyptus crebra* in the mid to upper layers of the formation occurs on hillsides and undulating areas, such as rocky skeletal soils. The majority of this forest type is found around the Hay Point–Mount Hector area and near Louisa Creek.

The eucalypt open forest associations of the Mackay Coast may intergrade and form a mixed unit. Mixed eucalypt open forest occurs in stony soils mainly on low hills. This mixed unit may adjoin *E. crebra* open forest.

Sandy seashore rainforest beach scrub

Beach scrub consists of many rapidly growing rainforest species. Some 194 (76 percent) native species have been recorded in this unit. This vegetation association is found in sheltered areas landward of the casuarina zone.

Beach scrub varies from relatively simple dune open scrub of a few rainforest species to more complex, rich closed forests. Species-rich closed forest up to 16m tall occurs at Shoal Point, Harbour Beach, Blacks Beach and Hay Point.

Rocky shore vegetation

Rocky shores occur at Shoal Point, Dolphin Heads, Slade Point, Lamberts Lookout, Mount Hector and Hay Point. Shingle beaches associated with headlands occur at Dolphin Heads and Lamberts Lookout. The seaward sides of these headlands are sheer and the vegetation on lower slopes is sparse and/or windswept. Closed grassland and closed herbland occur on the more exposed sections, with closed heaths and closed scrubs containing occasional emergents on less exposed sections. Species richness is very high, with 197 (70 percent) native species and 86 (30 percent) introduced species.

Disturbed

About 70 percent of all native vegetation has been cleared for sugarcane farming or residential purposes. Natural vegetation has also been disturbed, destroyed or severely modified by the establishment of pasture, small crop farming and other land uses including roads.

Dune vegetation on Bucasia Beach.

Dune vegetation zonation and management

Two distinct zonation patterns can be observed:

- along the exposed coastline, such as at Bucasia Beach and Harbour Beach. The zonation sequence includes a beach zone, foredune area, and a hind dune and swale area; and
- along the low-energy beach ridge coastlines such as Slade Bay Beach, Town Beach and McEwens Beach. The zonation sequence includes a tidal flat area, beach zone and beach ridge zone, behind which is an estuary zone.

Sandy shore stability and plant diversity depend on the presence of specialised seashore zonations. Most beaches along the Mackay coast require all of the major vegetation zones to maintain the specialist species required for natural beach stability.

In places such as Shoal Point Beach, northern parts of Blacks Beach and Town Beach, all strand vegetation has been eroded. Native plants cannot perpetuate where the processes of active erosion, fire, trampling and grazing persist. For example, fire-sensitive *Casuarina equisetifolia* var. *incana* and beach scrub vegetation are frequently replaced by open scrubs after an outbreak of fire.

As a result there are many disturbed sections of the coast that do not show an idealised zonation pattern. These areas are now heavily infested with invasive plants such as *Panicum maximum*, *Lantana camara* var. *camara*, *Psidium guajava*, *Agave vivipara*, *Opuntia stricta* and *Brachiaria mutica*.

Weed management

Weed infestation is a major factor affecting the native vegetation of the Mackay coast, and the control of these weeds requires active management. Within the Mackay study area, 310 species (28 percent) of the total flora are naturalised exotics not native to Australia. The area also has 56 species of environmental weeds that are seriously invasive.

The vegetation associations most susceptible to weed invasions are sandy seashores, melaleuca forests, rocky seashores, eucalypt open forests, riparian forests, beach scrub and freshwater treeless herbland. The vegetation associations that are relatively free of weeds include mangrove areas, hill and headland rainforest and lowland littoral rainforest.

The infestation of environmental weeds is slightly different from the occurrence of generalised weeds. Environmental weeds are more successful in riverine habitats. Moderately susceptible habitats are rocky shores, melaleuca swamps, sandy shores, beach scrubs and open forests. Habitats with low susceptibility are saline flats, lowland and hillside rainforests, and aquatic flats. Significant environmental weeds include *Dalbergia sissoo*, *Syzygium cumini* and *Psidium guajava*.

The presence of weeds alters the natural zonation patterns present in the Mackay area. For example, *Panicum maximum* and *Lantana camara* var. *camara* affect natural processes along Mackay's sandy seashores, especially in the *Casuarina equisetifolia* var. *incana* woodlands. When fires are lit, the fuel built up by *Panicum maximum* and *Lantana camara* var. *camara* causes hot fires that damage and effectively replace the fire-sensitive species *C. equisetifolia* var. *incana*. Natural establishment of tree seedlings is therefore retarded in dune areas degraded by dense covers of these weeds.

Vegetation conservation

The majority of remaining vegetation types could be preserved by incorporating relatively small areas of high habitat diversity in a series of green corridors. These corridors would be shaped as a 'T-square' incorporating a coastal strip and a riparian zone. The coastal zone preservation areas could include Slade Bay, Sandringham Bay and Dalrymple Bay T-square green corridors.

Collectively, these proposed terrestrial conservation areas cover less than four percent (about 1100ha) of the total study area. However, the areas include most of the remaining lowland and seashore vegetation types. These green corridors include about 75 percent of all locally endangered plants.

At least four important coastal sites lie within the mapped area.

1. **Louisa Creek gallery forest and estuary.** This site supports gallery forest and lowland closed forest (at Timberlands) surrounded by sugarcane farming and urban development. Currently this species-rich vegetation is almost free of weeds. The lower banks of Louisa Creek and adjoining hillsides near Dudgeon Point support important remnant stands of coastal eucalypt open forest. It should be noted that this site lies to the south of the study area.
2. **Sandringham Bay–Bakers Creek aggregation.** This wetland is listed as a wetland of national importance. The area includes diverse wetland sites at McEwens Beach and Dudgeon Point. Sandy Creek supports the only known coastal-zone population of *Eucalyptus ravertiana* in Queensland.

Slade Bay and McReady's Creek.

3. **Slade Bay corridor.** This coastal site enhances the outstanding landscape features of Mackay City. The Slade Point dune area and Mount Bassett rainforest have high conservation values, and the unique *Melaleuca leucadendra* open forest has very high conservation value. A substantial portion of the proposed Slade Bay T-square green corridor is already proclaimed as the Slade Point Reserve for Natural Resource Management. The incorporation of sites at McCreadys Creek, Andergrove, Slade Bay, Slade Point, Harbour Beach and Mount Bassett into a large group will result in a more resilient and diverse unit for conservation.
4. **Shoal Point corymbia/banksia dune open forest.** The area covers about 10ha of undisturbed *Corymbia tessellaris* and *Banksia integrifolia* open forest. This community is rare and atypical of the entire study area.

7 Fauna

Introduction

A review of the fauna observed in the Mackay study area has been undertaken with an emphasis on commercially valuable, and rare and threatened species.

The following discussion is presented in terms of major habitat types, which closely follow the vegetation associations. A summary map showing the distribution of these habitat types is given in figure 6. These habitats can be represented by three broad categories:

- wetland habitats;
- terrestrial habitats; and
- marine habitats.

Fauna of wetland habitats

Wetlands are a prominent feature of the Mackay study area and the habitat includes beaches, tidal flats, freshwater swamps, saline flats and estuaries.

The extensive wetland around Sandringham Bay and Bakers Creek has been listed as a wetland of national importance because it is an example of a marine and estuarine wetland in the Central Queensland Coast bioregion (Sattler and Williams 1999). It is significant because of the extensive expanse of intertidal and shallow-water habitat, the diversity of the shoreline and the extent of the mangroves. It is recognised as a nationally-important area for shorebirds.

The terrestrial wetlands of the study area, which include mangroves and freshwater swamps, are critical habitat for false water-rats. False water-rats, listed as vulnerable, have recently been rediscovered in the Mackay study area.

These wetlands are also considered to be of national importance for shorebirds. The Mackay region has been ranked sixth out of 13 regions in Queensland in terms of the total number of shorebirds present. The Mackay area is of international significance for the Mongolian plover, eastern curlew, great knot and sooty oystercatcher, and of national significance for the terek sandpiper, bar-tailed godwit and ruddy turnstone.

Wetlands in general, not only mangrove areas, are critical for many fisheries species. All tidal wetlands, including intertidal flats and channels, sandbars, river banks and claypans, contribute to ecosystem complexity, which enables fisheries resources to feed, grow and reproduce to complete their life cycles.

These areas are important habitat for a number of notable species including barramundi, grey mackerel, sea mullet, school mackerel, whiting, mud crab and tiger prawns.

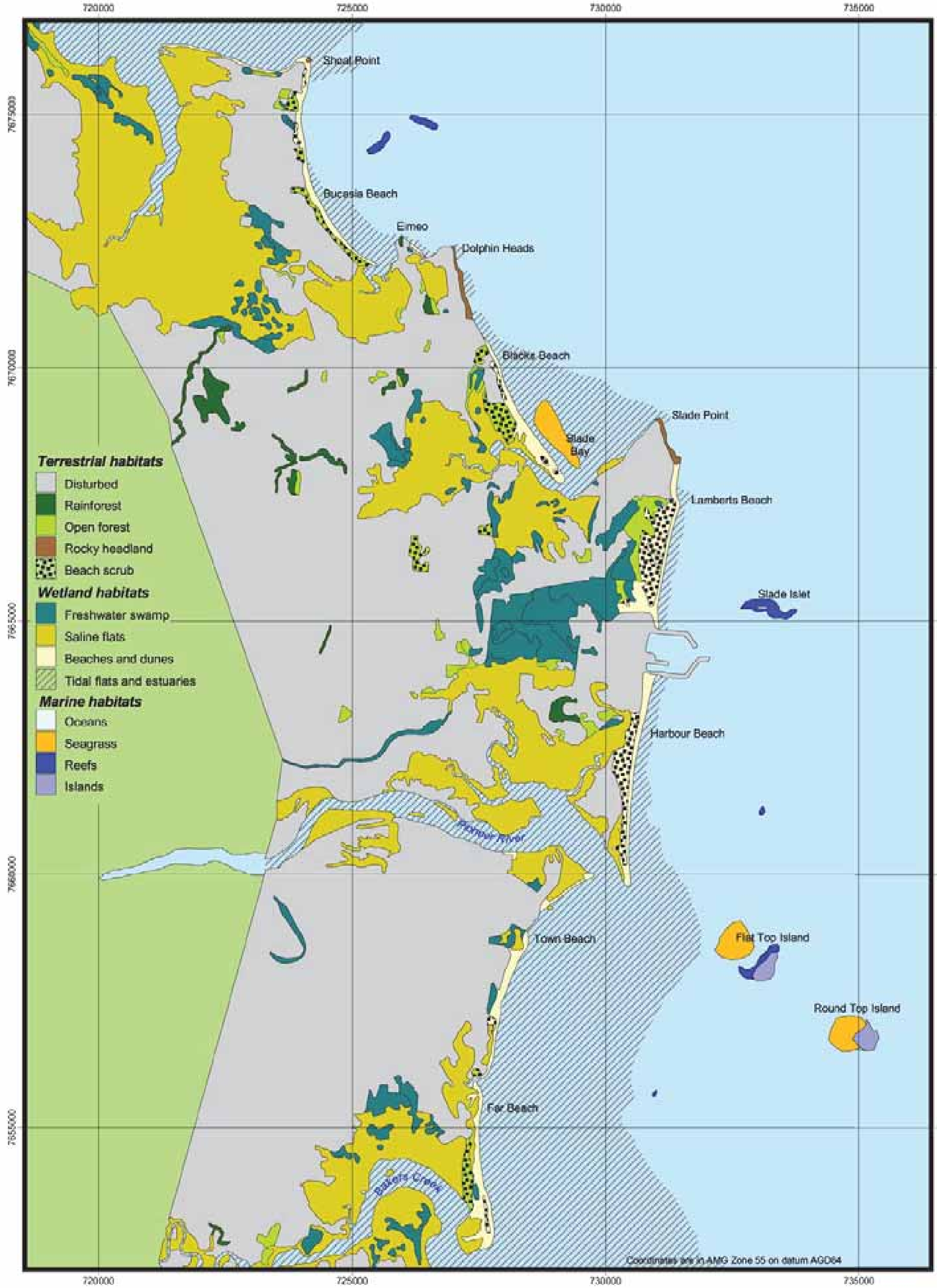
Beaches

The Mackay area is characterised by a number of wide sandy beaches. This habitat type includes sandy beaches and vegetated foredunes. Beaches are inhabited by a variety of organisms that are often specialised and usually restricted to this zone.

Shorebirds are the most conspicuous fauna inhabiting these beaches. The beaches are particularly important as high tide roosting sites. More than 1000 birds have been recorded roosting at high tide on Town Beach and Far Beach/Bakers Creek. Other important high-tide roosting sites where more than 300 birds have been recorded include Shoal Point, the Pioneer River mouth and an area south of the study area around McEwens Beach.

Notable species reliant on the beaches in the area include eastern curlews, little terns, beach stone-curlews and flatback turtles. There are eight resident pairs of beach stone-curlews, and about 50 to 60 turtles nest annually on the beaches.

Figure 6 Habitat map



Tidal flats and estuaries

A gentle slope sheltered from the prevailing south-easterly waves, the presence of river and creek entrances, and a large tidal range combine to form extensive intertidal sandflats and mudflats. The most extensive areas are in Sandringham Bay, the area around the mouth of Bakers Creek, and at Town Beach and Far Beach.

The tidal flats are important foraging habitat for the large number of shorebirds that congregate in the area. Extensive estuarine areas occur around the entrances to Alligator Creek, Bakers Creek, Pioneer River and Reliance Creek.

Estuaries are the meeting place of salt and fresh waters. Rich in nutrients, they are important habitats for adult marine animals and critical nursery habitat for the juveniles of many species. Notable species reliant on these estuaries include barramundi, mullet, eastern king prawns, banana prawns, crabs (mud and sand) and mackerel (school and grey).

Freshwater swamps

Freshwater swamps scattered throughout the area include areas of treeless swamps and melaleuca swamps. There are freshwater swamps at Shoal Point and Slade Point.

These swamps are characterised by seasonal periods of inundation and are an important seasonal habitat for a variety of organisms including wading birds. They are important feeding areas, and during periods of inclement weather are important roosting sites. Notable species reliant on these freshwater swamps include the black-necked stork and radjah shelduck.

Saline flats

Saline flats include intertidal herblands and mangrove areas. Extensive tracts are found around Reliance Creek, Slade Bay, Bakers Creek, Sandringham Bay and in the Bassett Basin around the Pioneer River.

The ecological values of saline flats have been well documented; they are ecologically highly productive, are important habitats for adult marine animals, and are critical habitat for juveniles of many marine species. Notable species that are dependent on these mangroves to complete their life cycle include barramundi, mud crab and banana prawn.

Bassett Basin is particularly important for barramundi as the freshwater ponds that flow into it create a unique tidal habitat. Other notable species that are dependent on saline flats include estuarine crocodiles.

Tidal flats are important foraging habitat for migratory shore birds.

Fauna of terrestrial habitats

The terrestrial habitats of the Mackay study area are dominated by the town of Mackay and the surrounding sugarcane farms.

Open forests

Most of the open forests found in the Mackay area are small, fragmented, remnant patches. The most extensive remnant block is behind Dudgeon Point. A large number of the mammals, birds, reptiles and amphibians found here are reliant on open forests as important foraging and nesting habitat. No notable species are known to be reliant on these open forests.

Rainforests

Isolated remnant rainforest patches occur around Reliance Creek, Louisa Creek, Mount Bassett, Blacks Beach and Dolphin Heads. A few strips of littoral rainforest occur along Bakers Creek, Louisa Creek, Reliance Creek, Leila Creek and Sandy Creek. Patches of beach scrub are dotted throughout some of the open forest and foredune areas. These occur behind McEwens Beach, Bakers Creek, Lamberts Beach, Harbour Beach, Blacks Beach and Bucasia.

The rainforests of the study area are small and fragmented. They are not likely to be large enough to harbour any significant populations of rainforest specialists. They are, however, important temporary habitat for a wide variety of generalist species that move from one area to another. They are used by rainforest specialists such as Torresian imperial-pigeons that feed in these areas as they migrate up and down the coast. No notable species are known to be reliant on these rainforests.

Rocky headlands

The study area's numerous rocky headlands include Shoal Point, Eimeo, Dolphin Heads and Slade Point. Rocky shore habitats support a wide variety of specialised fauna. Sooty oystercatchers, which are occasionally seen in the area, are a notable species usually associated with rocky shores.

Fauna of marine habitats

The tidal flats and estuaries of the area give way to a gently sloping ocean floor. A few reefs and moderate seagrass beds occur in the inshore waters. Flat Top and Round Top Islands are small continental islands just east of Mackay. The Great Barrier Reef lies approximately 180km east.

Operating within the Mackay study area are a trawl fishery, a tropical inshore finfish fishery, a crab fishery and a limited reef-line fishery. During the period from 1994–95 to 1997–98, the commercial fishing industry harvested on average 108t per annum of fisheries resources from the region. The main species harvested were king prawn, shark, banana prawn, crab, mackerel, mullet, bug, and barramundi.

Oceans

Oceanic waters are important habitat for a variety of pelagic and benthic species. Commercial species dependent on these waters include king prawns, banana prawns, crabs (sand and mud), bugs, mackerel, shark and mullet. Other notable fauna that frequent the oceanic waters of the study area include Irrawaddy dolphins and humpback whales.

Reefs

Reefs are present at Dudgeon Point, Oyster Rock, Flat Top Island, Dangerous Reef, Slade Islet, Slade Rock and around Shoal Point. They comprise rocky reefs and coral reefs. Rocky reefs attract a wide variety of marine animals because they are a prominent feature in an otherwise featureless marine environment, and coral reefs are well known for their diversity. Notable species reliant on these reefs include red-spot king prawns, loggerhead turtles and flatback turtles.

Seagrass beds

Small beds of seagrass occur at Round Top Island, Flat Top Island and Slade Point. Seagrass beds are ecologically important because they are highly productive, they trap and stabilise coastal sediment, and they are critical habitat for a number of commercial and protected species including banana prawns, tiger prawns, dugongs and green turtles.

Fauna and habitat conservation

Within the Mackay study area are a number of protected areas including fish habitat reserves at Sand Bay and Bassett Basin, Bakers Creek Conservation Park, and the Slade Point Reserve for Natural Resource Management.

It has long been recognised that the preservation of biodiversity requires the development of a comprehensive and representative system of protected areas. To achieve this goal, the assessment, planning and management of protected areas must be undertaken in a bioregional context.

Regional ecosystems are the primary unit for the development of a comprehensive and representative system of protected areas. It is thought that the identification and adequate preservation of a representative sample of the different regional ecosystems will ensure that biodiversity is maintained.

The Mackay study area lies within the Central Queensland Coast bioregion, which is centred on the high-rainfall coastal lowlands, hills and ranges around Mackay. Ten regional ecosystems occur in the Mackay study area (Sattler and Williams 1999, Ball 1998). Three of these ecosystems are classified as *endangered* and three are classified as *of concern*.

The endangered regional ecosystems that occur in the area are freshwater swamps, *Corymbia intermedia-Eucalyptus platyphylla* woodland and *Eucalyptus tereticornis* grassy woodland.

The usefulness of the regional approach to identifying and managing protected areas within the study area is limited because most of the remnant vegetation associations occur as small, fragmented areas. However, extensive areas of freshwater swamps occur throughout the study area.

The use of regional ecosystems is not appropriate for all species. This approach does not address the conservation needs of species that are rare and threatened, or have patchy distributions. Planning for the conservation of biodiversity should also include other complementary strategies focusing on the specific requirements of the particular species of concern.

Seventeen species listed in the Queensland *Nature Conservation Act 1994* have been recorded from the Mackay study area. The area is particularly important for flatback turtles, beach stone-curlews, eastern curlews and false water-rats. These species are reliant on the wetlands, particularly the mangroves, freshwater swamps, beaches and tidal flats of the Mackay study area.

A significant number of turtles nest annually on the beaches in the Mackay Region.

8 Meteorology

Introduction

Physical coastal processes in the Mackay region are directly affected by meteorological conditions. The dominant east to south-easterly trade winds have an important effect on wave conditions and are primarily responsible for the formation of sand dunes. Rainfall in coastal catchments has an important bearing on fluvial sediment supply, along with the growth of vegetation.

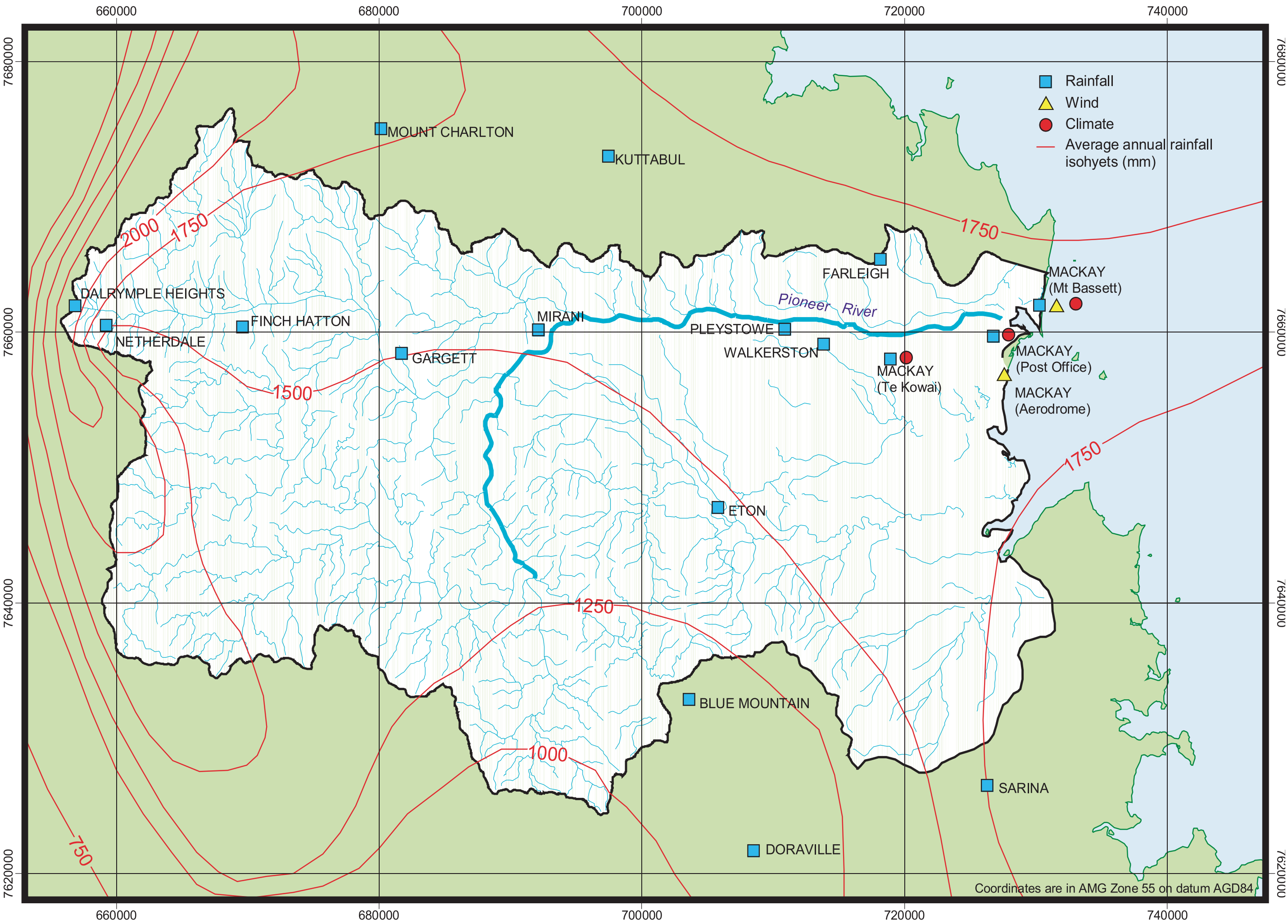
The most significant meteorological events occurring in the region are tropical cyclones.

Cyclones and tropical lows generate extreme conditions of wind, waves and water levels, and are often responsible for storm surges and high rainfall leading to flooding and short-term beach erosion.

Variability in the climate influences seasonal conditions. The three most dominant forms of variability affecting coastal Queensland are the El Niño/Southern Oscillation (ENSO), the Inter-decadal Pacific Oscillation (IPO) and greenhouse-induced climate change.

A review of the region's meteorology has been undertaken, primarily using temperature, rainfall, wind and miscellaneous climate data from the Bureau of Meteorology. The Queensland Department of Natural Resources supplied stream gauging data for the Pioneer River and tropical cyclone data were from Lourensz (1981) and the Bureau of Meteorology (figure 7 shows the Mackay region and the locations of the various land-based data monitoring sites).

Figure 7 Land–based monitoring sites: Pioneer River, Bakers Creek and Sandy Creek catchments and average annual rainfall isohyets (mm)



Climatic summary

The climate of the Mackay region is strongly influenced by the subtropical ridge of high pressure generally located to the south of the Australian continent. Cells of high pressure create an anticlockwise circulation resulting in a moist onshore flow of air, known as trade winds, which occur throughout the year. In winter, the ridge of high pressure is typically centred around 30°S and minimum rainfall conditions are experienced. In summer, high pressure systems are typically centred around 40°S. The onshore winds have a longer passage over warmer seas, resulting in a high moisture content of the air mass and higher rainfall. Synoptic patterns reflecting these typical conditions are shown in figures 8 and 9.

Figure 8 Typical synoptic pattern, winter (30 June 1991)

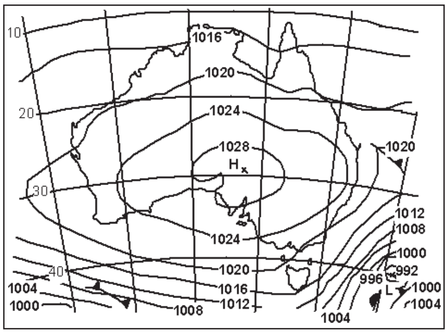
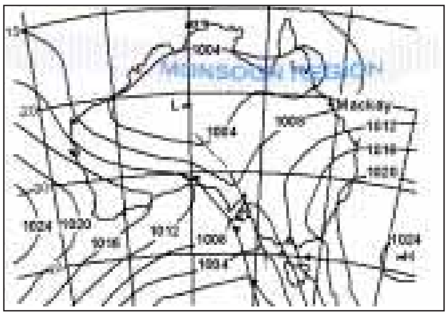


Figure 9 Typical synoptic pattern, summer (3 January 1991)



Near the coast, the local wind regime is affected by the sea breeze. The strength of the sea breeze is determined by the magnitude of the temperature difference between the land and the sea, and is generally greatest in the spring and early summer months, peaking in mid-afternoon. The direction of the sea breeze is approximately normal to the general coastline orientation, north-easterly in the case of the Mackay region. Wind is discussed in more detail elsewhere in this chapter.

In the summer months, tropical cyclones and tropical lows can exert considerable influence on northern Queensland weather patterns. These systems often interact with regions of high pressure over southern Australia to produce strong pressure gradients over the whole of eastern Australia. The Mackay region is too far south to be regularly affected by the north-west monsoon.

Average summer temperatures for Mackay range from a minimum of 22 degrees to a maximum of 30 degrees and average winter daily temperatures range from 11 degrees to 24 degrees. The maximum recorded temperature at Mackay (Mount Bassett) is 39.4 degrees and the minimum recorded temperature is 3.8 degrees. The temperature range generally increases with distance from the coast, primarily due to the cooling effect of sea breezes.

Humidity, unlike temperature, tends to decrease with distance from the coast. Highest values of humidity occur in the mornings of the late summer months (for example, the average level of 9 a.m. humidity in May is 82 percent). The minimum humidity falls to about 54 percent in August and September. The average humidity varies during the day, due mainly to the influence of the sea breeze (table 6 shows temperature and humidity data for the Mackay region).

Evaporation rates, linked to temperature and humidity, tend to be highest around November in the Mackay region, with a 7.8mm/day average. The lowest rates are typically in June, with a 3.4mm/day average. Locations further inland have higher evaporation rates than coastal areas (evaporation data are shown in table 7).

Table 6 Monthly and annual temperature and humidity statistics for Mackay in ºC

Station	Years of record	J	F	M	A	M	J	J	A	S	O	N	D	Annual
Mackay (Mount Bassett) Elevation 30.2m AHD 1959 to 1996														
Mean maximum	37	30.0	29.5	28.5	26.6	24.1	21.9	21.2	22.4	25.0	27.4	29.1	29.9	26.3
Highest maximum	37	37.2	38.7	34.7	33.8	29.2	29.1	29.7	29.3	32.2	34.9	34.9	39.4	39.4
Mean days >30°C	37	15.7	10.5	4.7	0.6	0.0	0.0	0.0	0.0	0.3	2.1	8.6	14.8	57.3
Mean minimum	37	23.4	23.2	22.1	20.0	17.1	13.7	12.7	13.9	16.5	19.5	21.8	22.9	18.9
Lowest minimum	37	17.2	17.8	13.1	12.0	7.1	4.6	3.8	5.0	7.9	10.6	14.9	15.3	3.8
Mean days <2°C	37	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Humidity **Mean 9 a.m.:**														
air temp. °C	37	27.3	26.8	25.8	23.7	20.8	17.7	16.9	18.7	22.0	24.9	26.6	27.4	23.2
wet-bulb temp. °C	36	24.0	24.0	23.1	21.3	18.6	15.4	14.5	15.9	18.3	20.5	22.3	23.4	20.1
dew point temp. °C	36	22.3	22.6	21.6	19.8	16.9	13.3	12.3	13.4	15.4	17.7	19.9	21.3	18.1
relative humidity %	43	75	79	78	80	80	77	76	74	68	66	67	70	74
Mean 3 p.m.:														
air temp. °C	45	28.6	28.3	27.5	25.8	23.4	21.2	20.4	21.4	23.6	25.9	27.5	28.5	25.1
wet-bulb temp. °C	45	24.5	24.6	23.7	22.1	19.9	17.4	16.7	17.6	19.2	21.1	22.8	23.8	21.1
dew point temp. °C	36	22.4	22.8	21.7	20.0	17.7	14.5	13.7	14.7	16.3	18.2	20.4	21.6	18.7
relative humidity %	43	70	73	72	71	71	67	67	66	64	64	65	67	68
Mackay (Post Office) Elevation 11.0m AHD 1870 to 1987														
Mean maximum	49	30.3	29.8	29.0	27.3	24.7	22.6	21.9	23.0	25.2	27.5	29.0	30.2	26.7
Highest maximum	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Mean days >30°C	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Mean minimum	50	23.3	23.1	22.0	19.4	16.1	13.4	11.7	12.5	15.4	18.6	20.8	22.5	18.3
Lowest minimum	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Mean days <2°C	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Mackay (Te Kowai) Elevation 13.7m AHD 1889 to 1996														
Mean maximum	69	30.9	30.3	29.5	28.0	25.7	23.7	23.3	24.6	26.7	28.8	30.4	31.3	27.7
Highest maximum	25	40.5	38.1	37.8	33.9	30.5	30.0	29.0	35.8	34.7	36.0	38.9	38.0	40.5
Mean days >30°C	21	17.4	11.0	8.3	2.5	0.1	0.0	0.0	0.4	1.9	5.0	12.9	15.6	75.2
Mean minimum	68	21.8	21.8	20.7	17.9	14.5	11.7	10.2	10.9	13.5	16.6	19.2	20.9	16.5
Lowest minimum	25	16.7	17.2	10.8	8.0	3.3	1.5	0.5	1.5	5.0	6.1	12.5	15.0	0.5
Mean days <2°C	20	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.0	0.0	0.0	0.0	0.0	0.5
Humidity **Mean 9 a.m.:**														
air temp. °C	68	27.8	27.0	26.1	24.0	21.0	18.3	17.6	19.4	22.7	25.7	27.5	28.3	23.7
wet-bulb temp. °C	67	24.3	24.2	23.4	21.4	18.6	16.0	15.2	16.3	18.6	20.9	22.4	23.7	20.3
dew point temp. °C	19	22.4	22.6	21.8	19.9	17.3	14.1	12.8	13.7	14.8	17.4	19.3	21.0	17.7
relative humidity %	43	73	79	79	79	79	78	76	70	63	61	62	66	72
Mean 3 p.m.:														
air temp. °C	10	29.2	28.3	28.0	26.4	24.0	22.3	21.8	23.0	24.9	26.6	28.0	29.8	25.7
wet-bulb temp. °C	10	24.4	24.4	23.5	22.2	19.6	17.6	16.6	17.3	18.8	20.7	22.1	25.2	20.4
dew point temp. °C	11	21.7	21.9	21.1	19.0	16.4	13.7	12.2	12.8	14.5	17.1	18.9	N/A	17.0
relative humidity %	22	66	70	68	66	64	59	58	55	54	56	58	63	61

Table 7 Mean daily evaporation (mm) for Mackay region 1889 to 1996

Station	Years of record	J	F	M	A	M	J	J	A	S	O	N	D	Annual
Mackay (Te Kowai)	20	7.1	6.1	5.7	4.8	3.7	3.4	3.5	4.5	6.0	7.3	7.8	7.5	5.5

Rainfall and hydrology

Rainfall within the Mackay region is highly variable and has a marked seasonality. Seasonal variations are due mainly to the processes associated with the migration of the subtropical ridge and the input from tropical low pressure systems (monthly rainfall averages for selected recording stations within the region are given in table 8).

Approximately 70 percent of the annual rainfall is recorded in the four-month period from December to March. The meteorological systems that influence this seasonal deluge are:

- tropical cyclones and rain depressions;
- upper troughs, with easterly inflowing winds;
- upper troughs and middle latitude fronts occurring in westerly winds; and
- convectional instability developing in south-easterly air streams, which mainly influence the coastal section.

Thunderstorms contribute greatly to monthly rainfall totals. The Department of National Development (1965) estimated that 70 to 80 percent of all September to December rainfall results from thunderstorm activity.

Annual rainfall totals are quite variable in the region. Throughout eastern Queensland, rainfall has a strong association with the Southern Oscillation and can explain as much as 40 percent of the rainfall variance (Partridge (ed.) 1994). Differences in air pressure between the regions of Darwin and Tahiti are a measure of the strength of the Southern Oscillation. When the Southern Oscillation Index is strongly positive, cyclone genesis and the subsequent paths are closer to the northern Queensland coast. Additionally, trade winds are stronger, resulting in a higher delivery of moist air and above-average rainfall.

Due to the very high proportion of annual rainfall occurring during the summer months, the failure of summer rains has historically led to drought conditions. The worst drought on record occurred during the period 1900 to 1903. Successive summer rains failed, leading to heavy stock and crop losses and flow in the Pioneer River was interrupted. Conditions of below-average rainfall leading to drought or semi-drought were recorded in the periods 1911 to 1916, 1918 to 1920, 1922 to 1926, 1930 to 1933, 1943 to 1949, 1951 to 1952, 1965, 1982 and 1992 to 1995.

The coastal topography has an important effect on the local meteorology. The rugged Clarke, Connor and Denham Ranges rise sharply from the coastal plains to elevations in excess of 1250m. In the immediate region of Mackay the onshore trade winds are deflected upwards (this is known as orographic uplift) as they approach the mountain ranges close to the coast, and this can result in heavy rainfall (figure 7 shows the distribution of average annual rainfall and clearly shows that the highest concentration of rainfall within the region is around Eungella on the Clarke Range). The amount of rainfall generally decreases with elevation but also increases immediately adjacent to the coastline.

The lowest monthly rainfall generally occurs in September. The distribution of the September average rainfall is quite different from the annual distribution. The maximum average rainfall recorded is not at an inland location but in Mackay.

The most intense rainfall recorded in the region occurred during the February 1958 rain depression. The Bureau of Meteorology (1965) reported that, at Finch Hatton, the 24-hour total for this event reached 878mm, Australia's second highest 24-hour rainfall total. Approximately 530mm of this rainfall was recorded over a five-hour period.

Flooding within the Mackay region occurs predominantly in summer and tends to be the result of high rainfall from tropical cyclones or rain depressions. The floods resulting from the February 1958 event caused widespread devastation, and bridges were completely washed away in neighbouring catchments. The Pioneer River at Mirani reached a record height of 52ft 10in (15.85m water depth) during this event (Bureau of Meteorology 1965).

Another extreme event captured on record resulted from rainfall associated with the devastating January 1918 cyclone. A total of 1411mm was recorded between 22 to 24 January 1918. The Pioneer River at Mirani peaked at a water depth of 14.1m (Bureau of Meteorology 1965). This event also caused flooding of rivers along the coast from Gladstone to Townsville (highest and lowest annual rainfall data within the Mackay region are shown in table 9).

Table 8 Average monthly and annual rainfall for Mackay region stations (mm) for 1870 to 1996

Station	Years of record	Annual rain days	J	F	M	A	M	J	J	A	S	O	N	D	Annual
Blue Mountain	40	N/A	209	220	149	60	36	54	38	17	25	42	65	131	1046
Dalrymple Heights	60	N/A	380	481	380	208	137	98	79	69	33	65	95	202	2220
Doraville	8	N/A	241	307	97	39	51	28	16	68	20	41	75	269	1113
Eton	40	N/A	326	288	226	85	53	47	35	22	22	42	67	150	1363
Farleigh Mill	40	N/A	397	383	317	160	103	75	39	29	35	47	74	162	1821
Finch Hatton	84	86	312	374	270	128	83	65	46	40	30	48	86	174	1653
Gargett	40	N/A	292	326	260	92	70	58	52	34	25	40	83	146	1478
Kuttabul	40	N/A	474	379	309	111	66	56	37	21	13	58	75	162	1761
Mackay (Mount Bassett)	37	129	298	306	281	148	113	61	44	29	14	38	86	193	1608
Mackay (Post Office)	80	110	335	318	308	152	94	68	41	26	40	46	74	164	1665
Mackay (Te Kowai)	107	118	353	347	289	141	93	61	37	28	29	45	79	183	1684
Mirani	27	N/A	265	336	219	112	92	41	38	35	22	53	98	193	1496
Mount Charlton	44	N/A	352	418	292	142	101	50	34	36	20	57	106	215	1826
Netherdale	40	N/A	339	321	267	115	66	94	50	33	34	46	70	152	1587
Pleystowe	40	N/A	377	349	299	128	77	58	41	33	35	49	78	152	1676
Sarina	88	105	379	396	295	131	81	56	39	31	26	56	106	201	1804
Walkerston	40	N/A	364	341	270	129	74	57	37	25	29	44	76	154	1600

Figure 10 shows a summary of flood peak discharges for the Pioneer River at Mirani for flows greater than $500m^{3/s}$ to the end of 1999. Flood flows corresponding to major rainfall events have been highlighted.

Mackay (Mount Bassett) is the official Bureau of Meteorology station for the region and has operated continuously since the closure of the aerodrome station in 1959. The Mackay wind recorder is situated close to the coast (Harbour Beach) but its location relative to Mount Bassett affects recordings from the south-west to north-west sectors. Exposure to the east is excellent, but topographic acceleration effects result in an overstatement relative to the offshore wind climate.

The predominant wind direction is the south-easterly trade winds, and this is reflected in the wind roses for Mackay (as shown in figure 11). The wind roses also show the effect of the north-easterly sea breeze, which is particularly noticeable in the afternoons during summer and spring months.

During autumn and winter, the passage of cold fronts embedded in the subtropical high pressure zone can result in periods of southerly and south-westerly winds. During the afternoons, the sea breeze influence causes a greater occurrence of winds from the south-easterly sector.Most extreme wind events in the region are associated with tropical cyclones. Tropical cyclone Kerry produced the highest recorded wind gust for the Mackay region. Wind gusts are in the order of 1.5 times greater than the average 10-minute wind speed. Recorded at 8.30am, 1 March 1979, the easterly wind peaked at 141km/h. Extensive wind damage associated with tropical cyclone Kerry was reported from Sarina to just north of Mackay. It is probable that much stronger winds could have occurred during tropical cyclones before instrumentation was installed.

Table 9 Highest and lowest annual rainfall values

Station	Highest annual rainfall (mm)	Lowest annual rainfall (mm)
Dalrymple Heights	4351	893
Doraville	2268	610
Finch Hatton	3581	603
Mackay (Te Kowai)	3455	632
Mirani	3078	509
Mount Charlton	3818	669
Sarina	3428	848

Figure 10 Pioneer River peak flood discharge data at Mirani

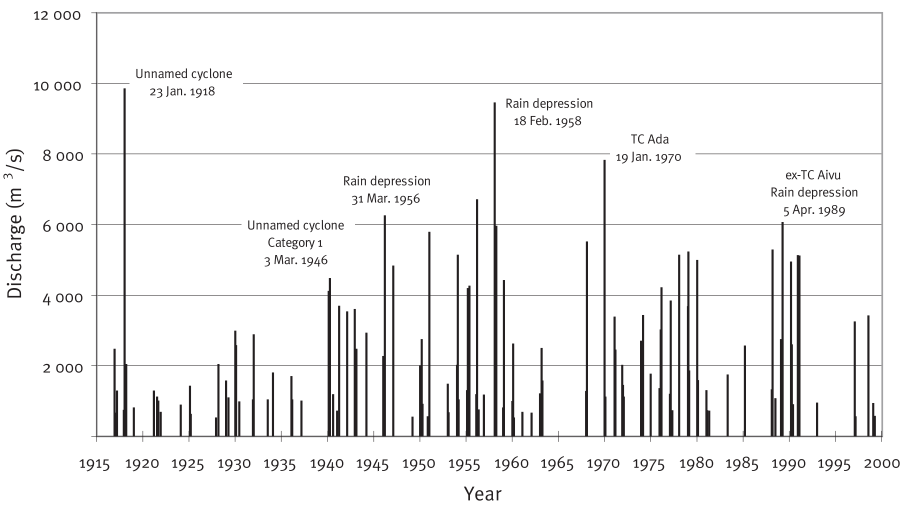
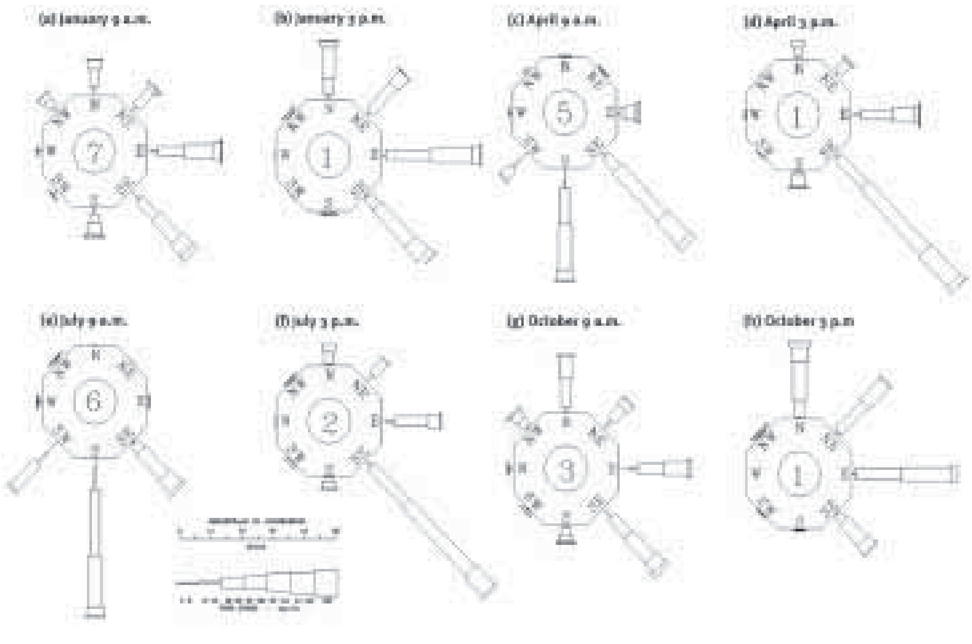


Figure 11 Mackay (Mount Bassett) wind roses



Tropical cyclones

A tropical cyclone can be described as an intense low pressure systems which form over warm ocean waters at low latitudes. In the southern hemisphere the horizontal wind circulation of a tropical cyclone rotates in a clockwise direction, as viewed from space.

For a weather system to be classified as a tropical cyclone, the central pressure must be below 1,000hPa and 10-minute mean wind speeds must exceed 63km/h (gale force). The Bureau of Meteorology categorises tropical cyclones according to the strongest wind gust (specified in table 10).

Table 10 Tropical cyclone severity categories

Category	Strongest gust (km/h)
1	<125
2	125–170
3	170–225
4	225–280
5	>280

Tropical cyclones affecting the Mackay region are usually generated in the Coral Sea. Several environmental conditions must be met for a tropical cyclone to form (Gray 1968, 1979):

- warm ocean waters (of at least 26.5 degrees) throughout a depth of approximately 50m;
- an unstable atmosphere, conducive to development of widespread thunderstorm activity;
- a minimum distance of at least 500km from the equator, to provide sufficient Coriolis force;
- a pre-existing near-surface disturbance with sufficient vorticity and convergence (tropical cyclones cannot be generated spontaneously); and
- low values (less than about 10m/s) of vertical wind shear between the surface and the upper troposphere.

Between November and April is generally regarded as the tropical cyclone season. The Bureau of Meteorology has compiled a database of all tropical cyclones in the Queensland region for the period from July 1909 to April 1995. Only six tropical cyclones crossed the coastline within 50km of Mackay City during this period and all occurred in the first half of the century (table 11 provides details of these events and figure 12 shows the tracks for major tropical cyclones that have affected the Mackay coast).

Figure 12 Tropical cyclone tracks impacting the Mackay region

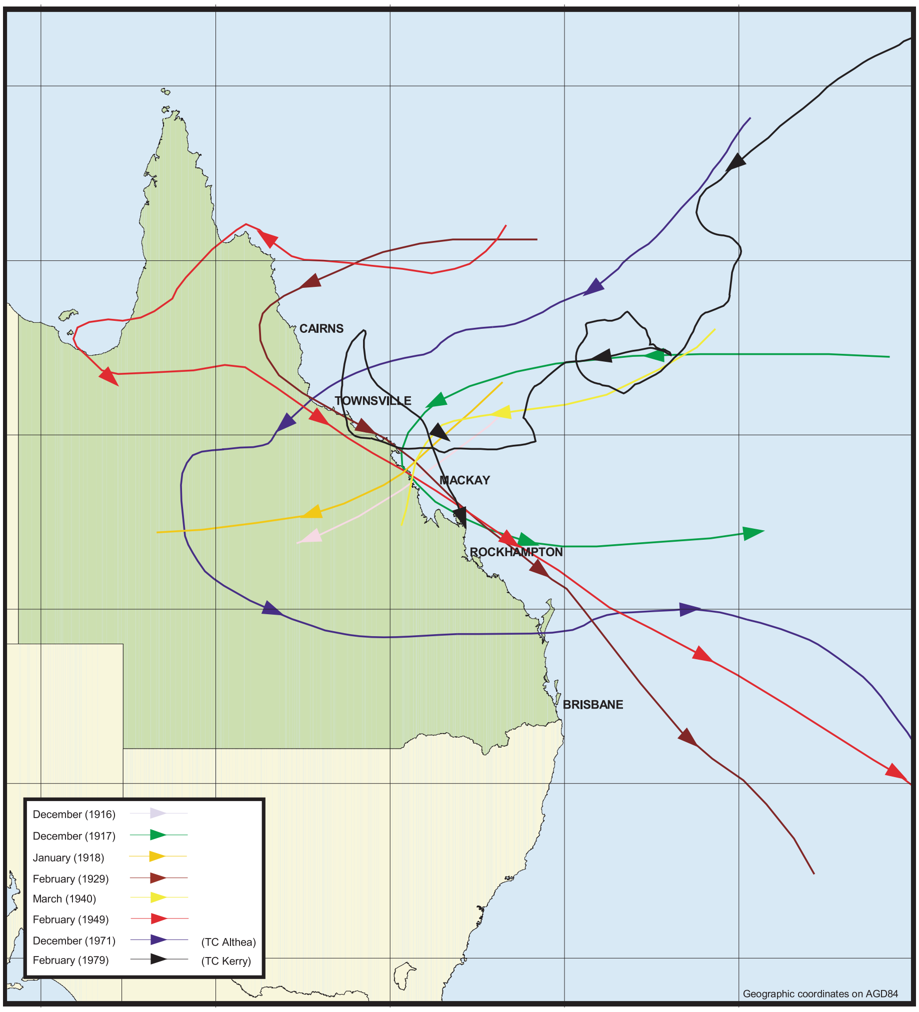


Table 11 Tropical cyclones that crossed the coast within 50km of Mackay City

Date	Central pressure (hPa)	Category
26 December 1916	985	1
15 December 1917	996	1
21 January 1918	933	4
27 February 1929	985	2
18 March 1940	987	1
8 February 1949	994	1

Proh and Gourlay (1997) examined the occurrence of tropical cyclones in the Queensland region using Bureau of Meteorology data. Their data were re-analysed using a different statistical method (figure 13 provides the distribution of the average annual occurrences for all cyclones in the period 1959 to 1996). It highlights the expected high incidence of these events in the Mackay region.

The region can be influenced by cyclone events that do not necessarily cross the coast in close proximity. On Christmas Eve 1971, tropical cyclone Althea crossed the coast adjacent to Townsville, approximately 325km north-west of Mackay, causing noticeable impacts. Similarly, although tropical cyclone Kerry did not pass over the Mackay region, it was still significant enough to cause record wind gusts.

The most significant tropical cyclone to affect the Mackay region since 1909 occurred in 1918, when an unnamed cyclone crossed the coast at approximately 7.30am on Monday, 21 January. Early that morning, the barometer on Flat Top Island had steadily dropped to 948hPa, until the needle rested on the rim of the barometer and was unable to record any lower readings. In Mackay, the wind swung from south to east to north at the height of the cyclone, indicating that the eye passed slightly to the north of the town. The official pressure recording was 933hPa (Mackay Post Office) however, the pen of the barogram had rested on the flange at the lower end of its limit for half an hour.

The cyclone had a devastating impact on Mackay. A storm surge of 3.7m accompanied the cyclone. Over the period 22 to 24 January, 1411mm of rainfall was recorded, resulting in an estimated peak flood discharge of more than 9800m^3/s in the Pioneer River.

As a result of the cyclone, 31 people perished and property damage was estimated at £1million (1918 value). Residents reported that wind caused most of the damage to property, but nearly all fatalities resulted from the impact of the storm tide.

Climate variability

The climate fluctuation known as El Niño/ Southern Oscillation (ENSO) is the most prominent form of climate variability across the Indo-Pacific region. In northern Australia it has a statistically significant impact on rainfall and other weather elements including tropical cyclones (Nicholls 1992; Nicholls et al. 1998; Callaghan and Power, submitted).

The phenomenon is closely coupled with characteristic changes in upper ocean temperature patterns across the tropical Pacific Ocean. The period of the ENSO cycle varies from a season or two to a few years.

The El Niño/Southern Oscillation is commonly described by the Southern Oscillation Index (SOI). The El Niño phase (corresponding to negative SOI) is characterised on a statistical basis by lower rainfall and fewer tropical cyclones near the Queensland coast. Upper ocean temperatures are typically lower around northern Australia and warmer in the Equatorial Central to Eastern Pacific. The opposite La Niña phase is characterised by higher rainfall, larger numbers of tropical cyclones and more wind. Upper ocean temperatures are generally warmer around northern Australia and lower in the Equatorial Central to Eastern Pacific.

It is important to understand that every ENSO event is different, and the statistically more probable variations do not occur over every region during every event (figure 14 shows the cumulative trend in monthly SOI since 1957). It is evident that the overall trend was dominated by El Niño events from the mid-1970s to mid-1998.

Recently, Power et al. (1999) highlighted the potential importance for the Australian climate of a long-term cycle of sea temperatures in the Pacific Ocean. This cycle is thought to be linked with changes in the slow, large-scale thermo-haline circulation of the Pacific Ocean. The oscillation is known as the Inter-decadal Pacific Oscillation (IPO), and it occurs on time scales of 10 to 30 years or so. It also appears to have a modulating effect on the way that ENSO events evolve. Callaghan and Power (submitted) describe a possible modulating effect of the IPO on tropical cyclone activity, including evidence to suggest that damaging impacts in Queensland are more likely during the negative or cooler Pacific phase of the IPO.

Figure 13 Annual average occurrence of tropical cyclones, 1959 to 1996 (based on Proh and Gourlay 1997)

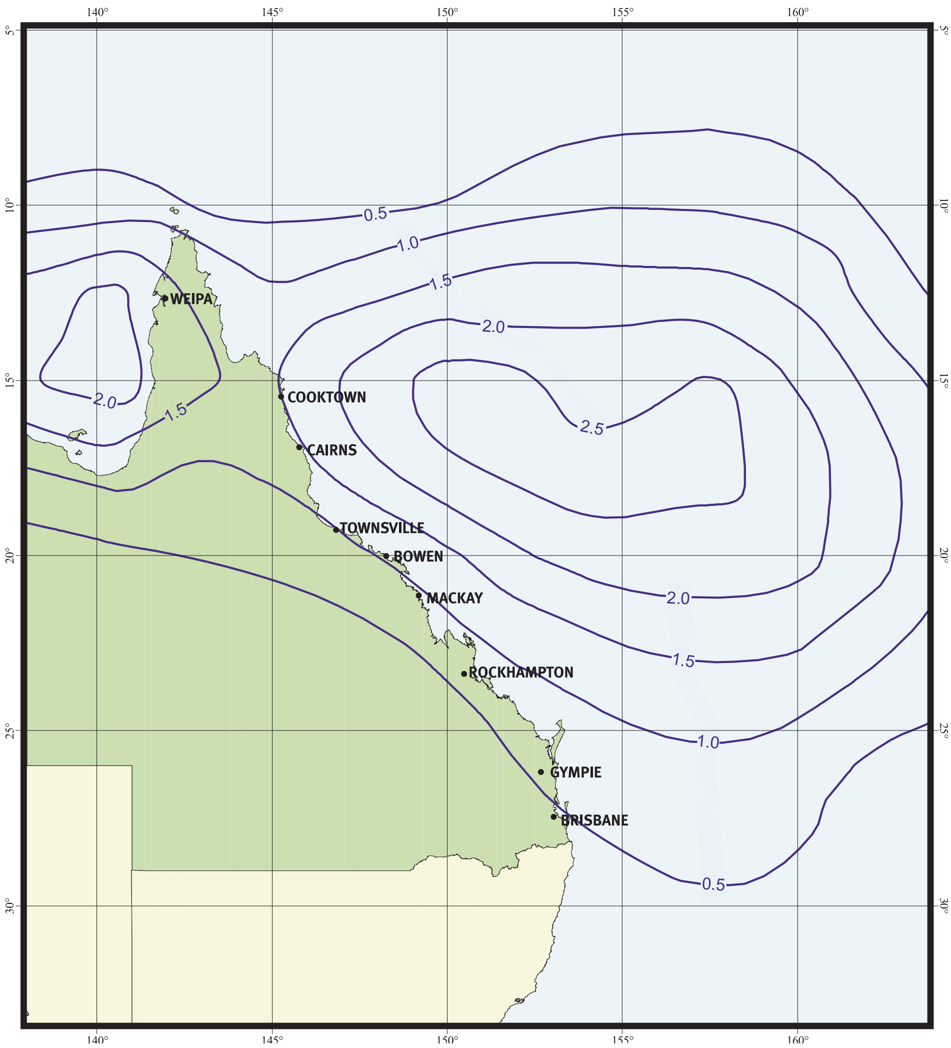
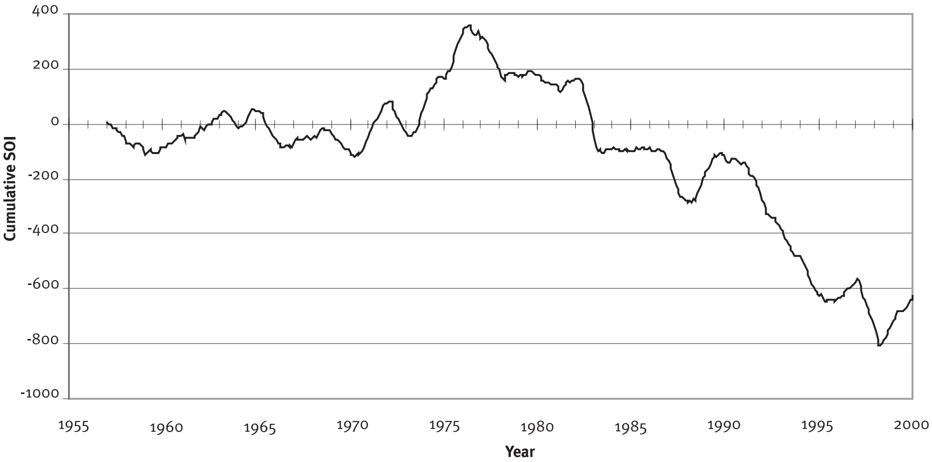
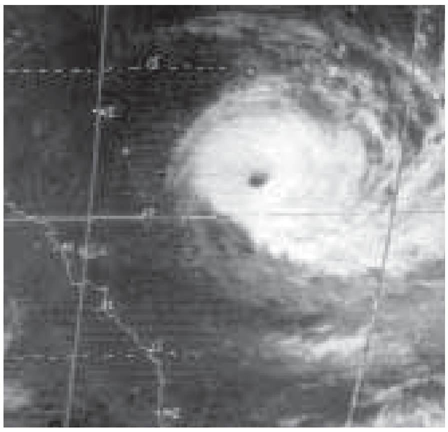


Figure 14 Cumulative SOI data





Satellite photograph of TC "Kerry" in the Coral Sea, April 1979 (Source: Bureau of Meteorology)

Climate change

The potential impact of global warming arising from the enhanced greenhouse effect has become a major scientific and social issue in recent years. Greenhouse warming occurs when solar radiation absorbed by the earth is re-emitted as heat energy back into the atmosphere, where it is partly trapped by greenhouse gases. These gases then re-emit the radiation in all directions, further warming the atmosphere and the earth's surface. The process is a natural one; without these gases, the earth's surface would be approximately 33 degrees cooler. However, human activities have markedly increased the level of greenhouse gases in the atmosphere. This is expected to raise global temperatures, leading to changed climates.

The World Meteorological Organization's (WMO) December 1998 annual Statement on the Global Climate indicated that, globally, the 1990s were the warmest decade since instrumental measurement started in the 1860s. Recent scientific evidence based on pre-instrumental proxy climate data, mostly from sites in the northern hemisphere, indicate the 1990s were the warmest decade and the 1900s the warmest century during the past 1000 years.

A global consensus report on climate change is provided by the Intergovernmental Panel on Climate Change (IPCC) of the WMO and United Nations Environment Program (UNEP). It is updated approximately every five years following an intensive review by hundreds of scientists. Although tropical cyclones have apparently varied on a regional basis over decadal time scales, IPCC (1995) and Henderson-Sellars et al. (1998) highlight uncertainties in past records and the difficulties in discerning any long-term trends. Henderson-Sellars et al. (1998) indicate the possibility of a modest increase in the maximum potential intensities of tropical cyclones.

9 Water levels and currents

Introduction

The Mackay coastal region is subject to considerable variation in water levels and water flows caused by a number of major influences. The daily astronomical tide, with a maximum range of more than 6m, has a dominant effect and the outflow of the Pioneer River has an important localised effect. Seasonal large-scale weather patterns, interspersed with tropical cyclones or other storm events, can also have a marked influence on regional water levels and currents.

A detailed assessment of the hydrodynamics of the region has been undertaken for this study, including:

- a review of all available information and previous studies;
- the acquisition of water level and current data throughout the study area, including vertical current profiling; and
- numerical hydrodynamic modelling of the tidal influence at both the regional scale and local scale.

Mean sea-level

Mean sea-levels are affected by geological (eustatic and tectonic) changes and potential anthropogenic (human-induced) related impacts. Although changes in the mean sea-level occur very slowly, they are highly significant in the understanding of the coastal morphology of the region. The characteristics of a coastline comprised mainly of sandy beaches are highly responsive to changes in mean sea-level.

Over geological time scales, the Holocene period (from 10,000 years BP) has featured extensive variations in mean sea-level, primarily in response to global temperature changes. These changes have been a result of the combination of specific sea (eustatic) and land (tectonic) movements, each relative to the other. It is commonly accepted that the present sea-levels were reached approximately 6500 years BP. Before this, during the most recent glacial period, sea-levels were in the order of 160m below modern levels.

Following the relatively rapid post-glacial sea-level rise during the early Holocene, mean levels have been relatively stable at present levels.

There is evidence that the local sea-level around Mackay may have been as much as two metres above modern levels around the mid-Holocene (Hopley 1983; Masselink and Lessa 1995). This is discussed further in the description of the geological history of the region.

A review of modern sea-level records by Gornitz and Lebedeff (1987) indicates a trend of about one to two mm/a rise in mean sea-level globally, attributed in this instance to natural eustatic effects alone. The National Tidal Facility (NTF) has undertaken an analysis of long-term sea-level observations at a number of locations on the Australian coastline (PCTMSL 1999). The analysis indicates an overall average of 0.3mm/a increase in mean sea-level based on a network of 27 tide gauges with a minimum of 23 years of data.

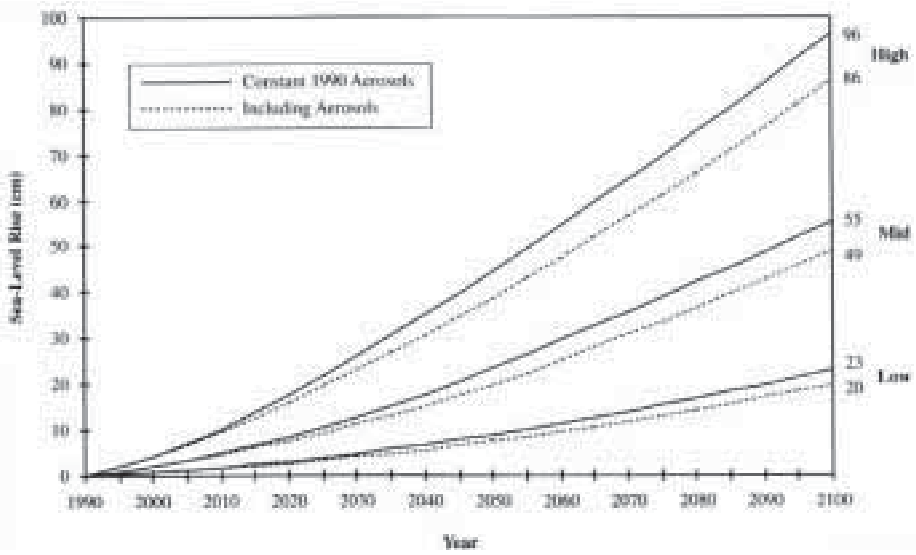
Tidal records have been available in the Mackay region since 1948 and, albeit with some considerable gaps, exist in a digitised form reaching back to 1960. The Beach Protection Authority's storm tide gauge has been operating in Mackay Harbour since 1975. Assuming no tectonic contamination of the record, an increasing trend of 1.24mm/a has been determined by the NTF for 24.3 years of data (PCTMSL 1999).

Anthropogenic changes due to the greenhouse effect may also be capable of raising coastal water levels by a further 0.2 to 0.9m over the next 100 years if expected climate change trends are not reversed. There is indisputable evidence that levels of greenhouse active gases such as water vapour, nitrous oxide, ozone and chlorofluorocarbons in the atmosphere have steadily increased since the industrial revolution, mainly due to the burning of fossil fuels.

One possible consequence of these increasing levels is a rise in the mean global temperature. As a result, anthropogenically induced eustatic sea-level rise may also occur. While debate continues about the possible natural feedback mechanisms that may be occurring to attenuate these effects, and continued efforts are made to reverse the trend in greenhouse emissions, it is prudent to consider the possible range of impacts such a sea-level rise might have on a coastal region such as Mackay.

Since greenhouse gas emissions depend on future human activity, predictions of their effects cannot be made with certainty. The United Nations International Panel on Climate Change has developed a series of likely scenarios, which are designed to investigate a range of possible climate impacts through the use of sophisticated numerical climate models (IPCC 1995). The current best estimate is that sea-level will rise by 49cm by the year 2100, with a range of uncertainty of 20 to 86cm. Over a 50-year planning period to 2050, the best estimate of greenhouse-related sea-level rise is 20cm (this scenario is shown in figure 15).

Figure 15 1990 to 2100 sea-level rise for scenario IS92a (after IPCC 1996)



Tides and tidal flows

The Mackay region experiences some of the highest astronomical tides in Australia, exceeded only by those of the north-western Australia coastline between Port Hedland and Darwin. The large tide range results in strong tidal streams, often in excess of 0.5m/s in some locations. In conjunction with the relatively flat beach profiles, a tidal excursion of more than 2.5km is common in some areas, notably in the coastal section south of the Pioneer River entrance.

The gravitational attraction of the moon and the sun combine to generate the tidal variation in the world's oceans. This variation is in the form of long-period waves, which travel through the ocean basins in complex patterns dictated by the seabed topography and the shape of the coastlines. In the south-western Pacific Ocean the main tide wave approaches the Australian east coast from an easterly direction.

In the Mackay region, the tide wave is considerably modified by the influence of the continental shelf and the Great Barrier Reef. The tide is semi-diurnal (high water occurs twice daily) with a marked diurnal (daily) inequality.

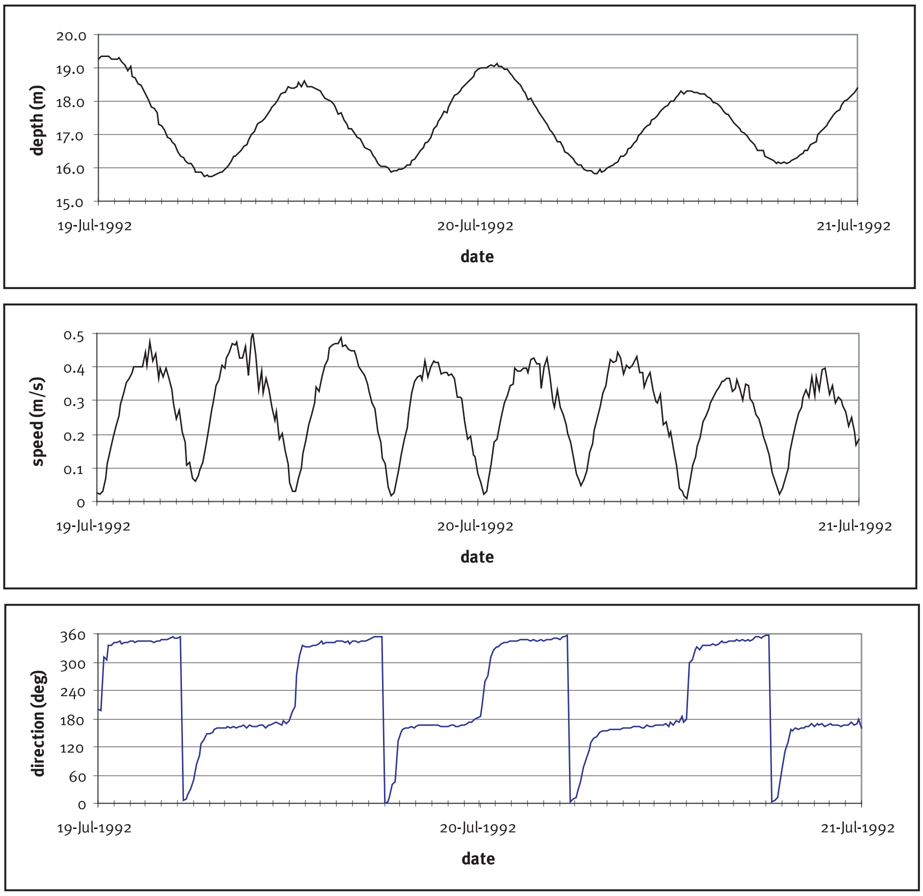
The relatively shallow water of the continental shelf and the topography result in a significant amplification, which reaches near-resonance in the vicinity of Broadsound, to the south of Mackay. The mean spring range at Mackay is 4.56m and the range from highest to lowest astronomical tide is 6.41m. Strong tidal flows are driven by the variation in tidal characteristics along the coast.

The shallow water also causes a distortion and a noticeable asymmetry of the tide wave and associated tidal flows (figure 16 shows an extract of water level and current data recorded at Oom Shoal 7km east of Slade Point and 9.9m depth).

The following characteristics are noted:

- there is a marked variation in successive high waters but little variation in successive low waters;
- the flood tide runs south towards Broadsound;
- low water occurs 3h before mean sea-level but high water occurs 3.3h after mean sea-level; and
- on average, the ebb stream runs for 6.3h and the flood stream runs for 6.2h, although variations of up to 20min on these times have been observed.

Figure 16 Data summary, S4 current meter (Oom shoal) 19–21 July 1992



A consequence of these effects is a slightly stronger ebb stream to the north and a phase lag of the tidal stream with the times of high and low water. Peak ebb flows occur about one hour after high water and the peak flood stream is approximately one hour after low water.

The characteristics of the tide can be described accurately by a set of harmonic constituents derived from a long time-series of water level observations. A standard harmonic analysis yields more than 100 constituents that can be used for accurate tidal predictions. The longest periodicity considered in a harmonic analysis is generally taken as 18.6 years. The highest predicted water level over an 18.6 year 'epoch' is known as the Highest Astronomical Tide (HAT). Correspondingly, the lowest predicted water level is the Lowest Astronomical Tide (LAT), which is commonly used as a chart datum for reporting depths for navigation purposes.

Table 12 shows the tidal planes for Mackay Outer Harbour, the standard port in the region, taken from the Queensland Tide Tables (Queensland Transport 1999). The Beach Protection Authority's storm tide gauge, in operation since 1975, is the primary tide gauge in the region (figure 17 provides percentage exceedance data for Mackay Outer Harbour tides).

Table 12 Predicted tidal planes for Mackay Outer Harbour

	Relative to chart datum (m)	Relative to AHD (m)
Highest Astronomical Tide (HAT)	6.41	3.47
Mean High Water Springs (MHWS)	5.28	2.34
Mean High Water Neaps (MHWN)	4.06	1.12
Mean Low Water Neaps (MLWN)	1.94	−1.00
Mean Low Water Springs (MLWS)	0.72	−2.22
Lowest Astronomical Tide (LAT)	0.00	−2.94

As part of the field data acquisition undertaken for this study, specific measurements were made to investigate the tidal characteristics of the region. Simultaneous water level and current recordings were obtained for a number of locations as shown in figure 18. These were made by pressure recorders and electromagnetic current meters deployed on the seabed, along with vessel-mounted current meters.

A series of recordings were obtained with an acoustic doppler current profiler (ADCP), deployed from a small vessel, which enabled direct measurement of the vertical structure of the flow. Data was obtained over a number of transects in the vicinity of Mackay Harbour and the adjacent coastline.

Figure 17 Current measurement sites

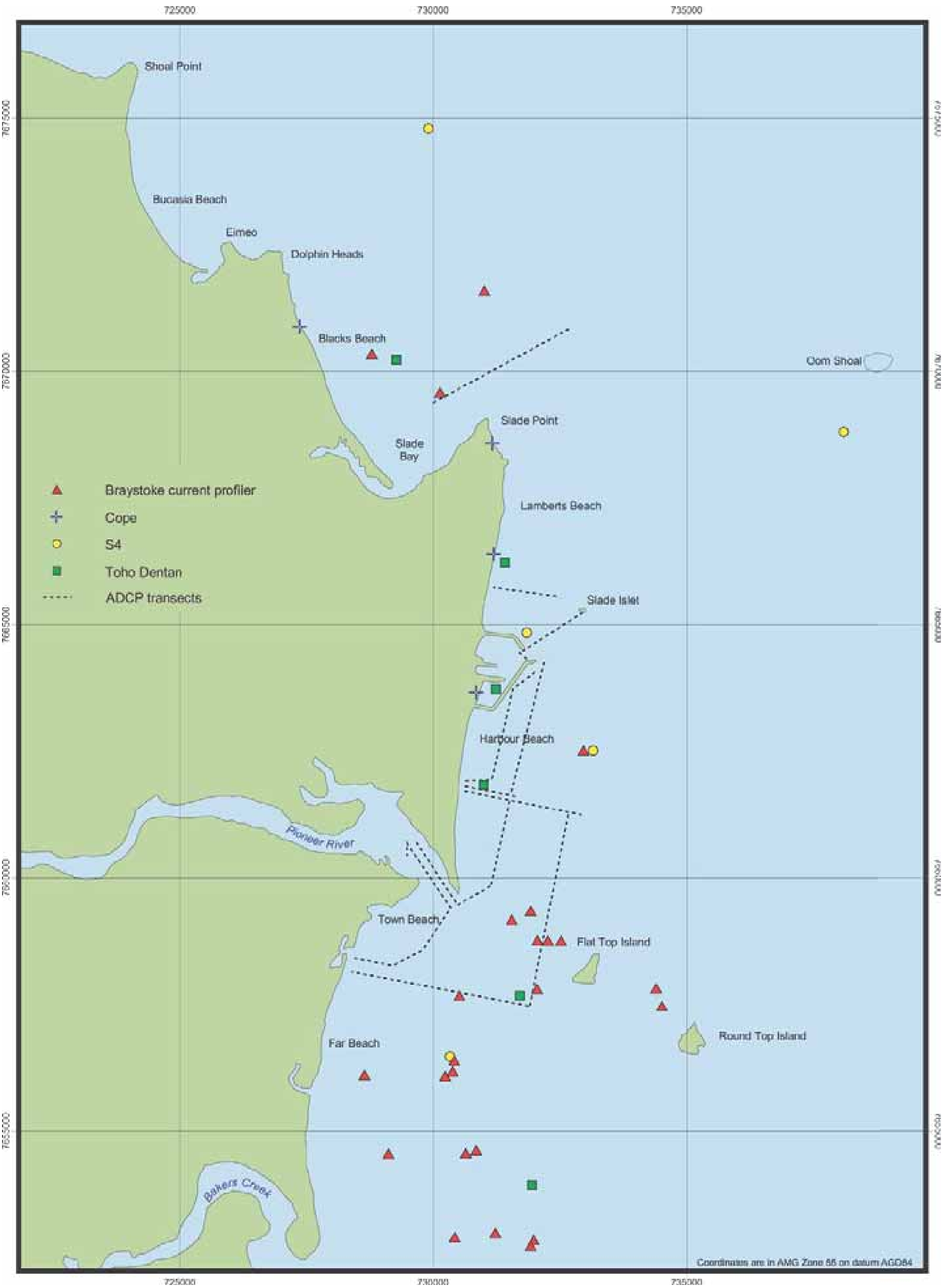


Figure 18. Water level exceedance plot, Mackay Outer Harbour

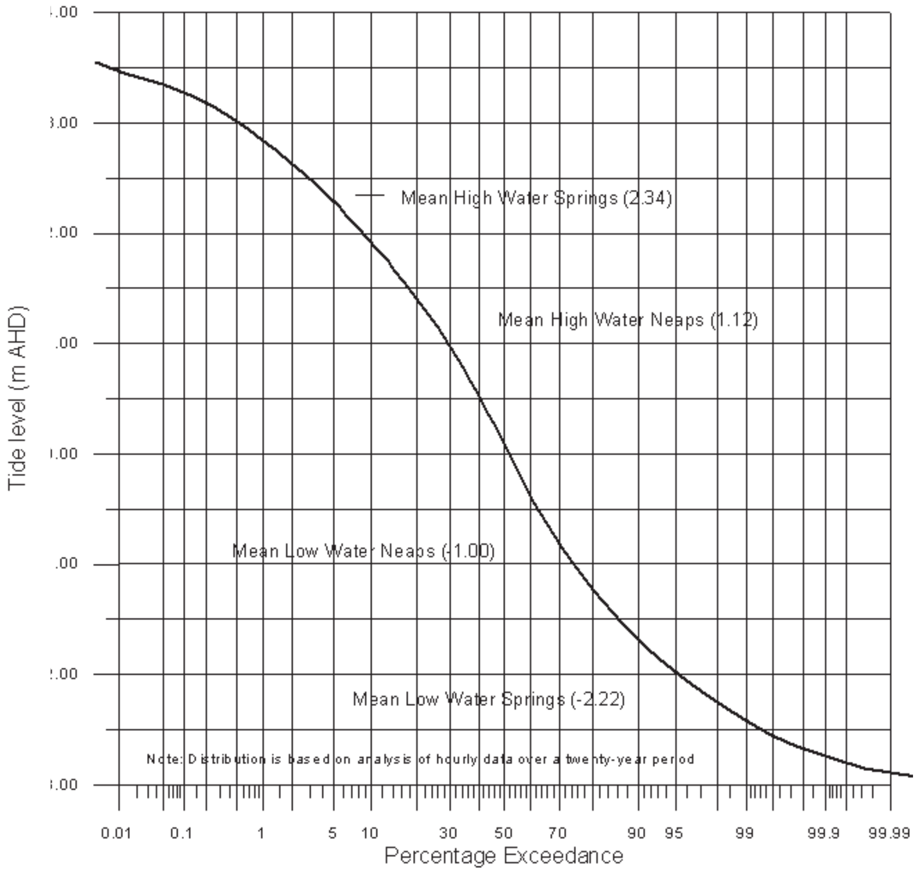
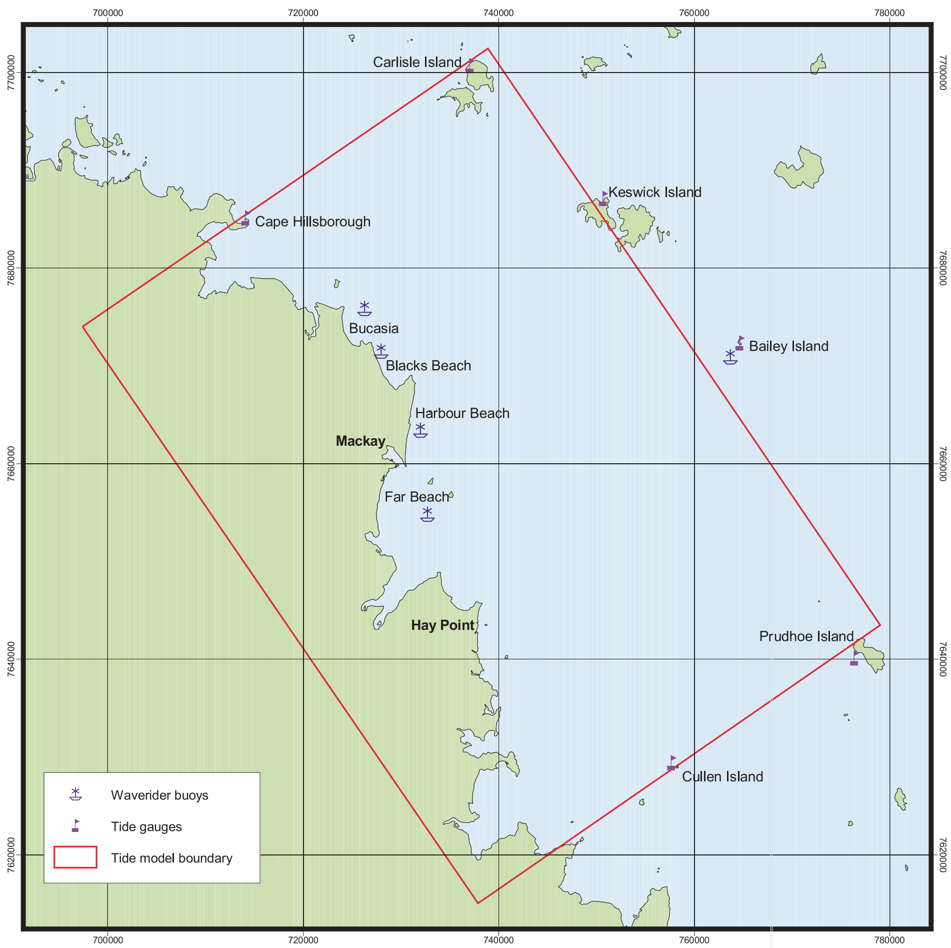


Figure 19 Location of Mackay tide gauges and waverider buoys



Numerical modelling

To assist in the quantification of tidal flows across the study region and to extend the value of the limited field measurements, numerical modelling of tides in the Mackay region was undertaken using two models developed in the MIKE 21 HD modelling system (DHI 1998). MIKE 21 HD simulates unsteady two-dimensional flows in one-layer (vertically homogeneous) fluids by solving the vertically integrated form of the Navier-Stokes equations using an alternating-direction, implicit finite-difference technique. A review of the field data of vertical current profiles indicated that the flows are well mixed and the depth-integrated assumption of the two-dimensional model is justified.

A regional model (50 by 70km) with grid size of 500m was prepared to cover the coast between Cape Hillsborough and south of Hay Point (the extent of the model is shown in figure 19). The boundaries of the model were positioned to coincide with locations of water level recording stations. Nested within the regional model, a local model (16 by 36km) was constructed with grid size of 100m.

The open boundary conditions of the regional model were derived from the available water level measurements, which included typical spring and neap tide periods. Bed friction and eddy viscosity (turbulent mixing) parameters were calibrated to provide the optimum match between simulated and recorded water levels and currents at a range of locations in the model domain.

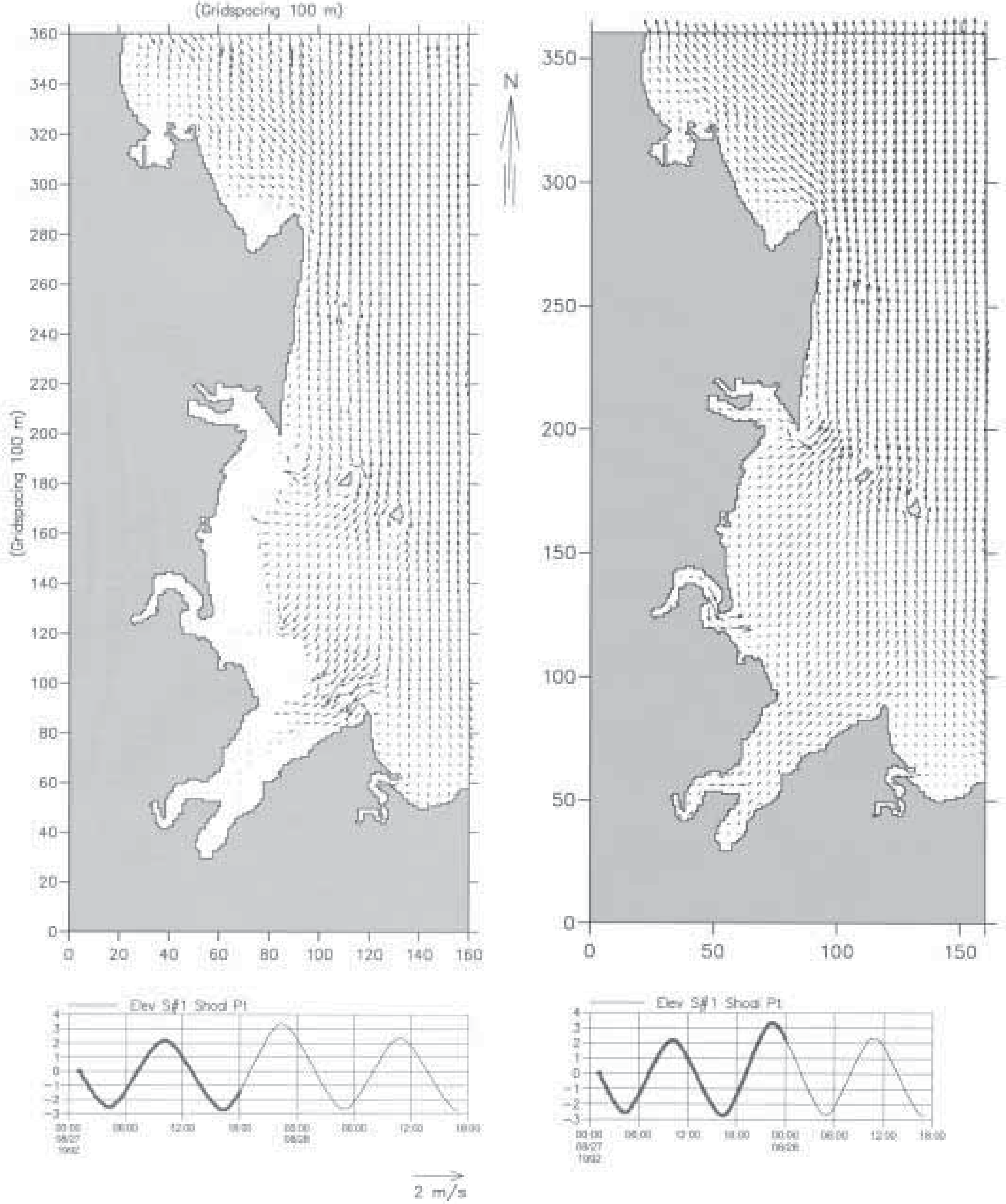
Boundary conditions for the local model were derived from the regional model. The operation of the model was then verified against recorded water level and current data at locations close to the centre of the study area.

A representative distribution of peak mean spring flows for ebb and flood streams (figure 20) indicates tidal currents in the order of 0.5–0.6m/s throughout the region.

Characteristics of the tidal flows include:

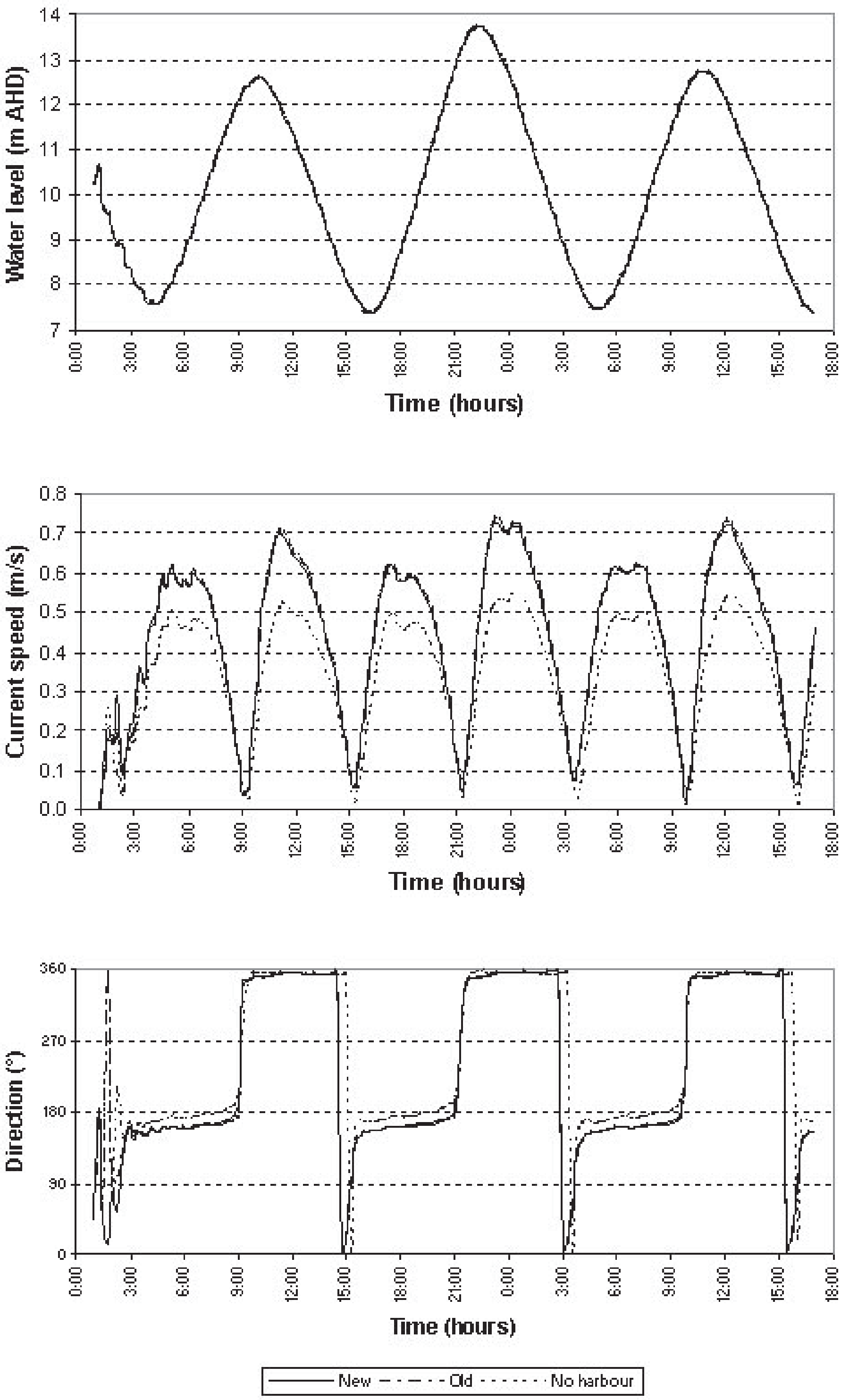
- the primarily cross-shore flows at low water levels on the tidal flats;
- the disturbance that various features including headlands, islands and reefs cause to the overall flow patterns; and
- the influence of the harbour walls.

Figure 20 Peak mean spring flows



An examination of the effects of the harbour walls on the tidal flows was undertaken (figure 21 shows typical tidal velocities for a point approximately 500m seaward of the harbour before and after construction) and indicates that velocities may have increased by up to 30 percent. A similar examination of the relative effects of the recent harbour extension works has shown that no detectable change in typical tidal flows in this area has occurred.

Figure 21 Effect on tidal velocities, pre and post Harbour construction



Other influences

The dominant oceanic current along the eastern Queensland coast is the East Australian Current. This is part of the general South Pacific circulation and extends from the Coral Sea along the coast to southern New South Wales. A description of the East Australian Current is given by Cresswell (1987).

At locations near Cape Moreton and Cape Byron the current has been observed to flow at velocities in the order of 2m/s, but in the Mackay region the effect of the East Australian Current is negligible. The main component of the flow occurs near the edge of the continental shelf seaward of the Great Barrier Reef. The relatively high flow resistance of the reef matrix reduces the component of the East Australian Current inside the Great Barrier Reef to almost zero.

Freshwater flows can have a significant localised effect on coastal hydrodynamics. The Pioneer River is the region's major catchment system and episodically produces high discharge flows that can extend large distances into coastal waters. Discharges of 4,000m^3/s are known to have caused flooding in Mackay, although peak flows of up to 10,000m^3/s have occurred. The interaction of high-discharge flood flows with nearshore tidal flows is highly dependent on the state of the tide (figure 22 shows indicative model results for a medium flood event in the Pioneer River interacting with the nearshore tidal currents).

Short-term variations in water levels and currents in the region are primarily caused by wind. The standard persistent south-easterly trade wind flow in the region during the dry season months leads to a weak northerly current along the coast. This seasonally dependent flow results in an associated water level increase, which can be extracted from the harmonic analysis of tide data.

Of particular interest are high wind events such as tropical cyclones, which can significantly affect coastal water levels and short-term currents. Storm surges are a major hazard in the region.

Extreme water levels

The understanding of the likely effects of extreme events is important for quantifying potential coastal hazards of coastal erosion and storm tide inundation. A severe storm such as tropical cyclones can be expected to initiate significant localised coastal change due to the combined impact of increased water levels, extreme currents and high wave attack. This may result in loss of upper beach, possible dune breaching or overtopping, and reshaping of offshore banks and shoals. The possible coexistence of a storm tide with an existing flood condition in the Pioneer River would increase river flood levels above expected values.

Figure 22 Model results, Pioneer River medium flood event ($5000m^{3/s}$)

a) ebb tide

b) flood tide

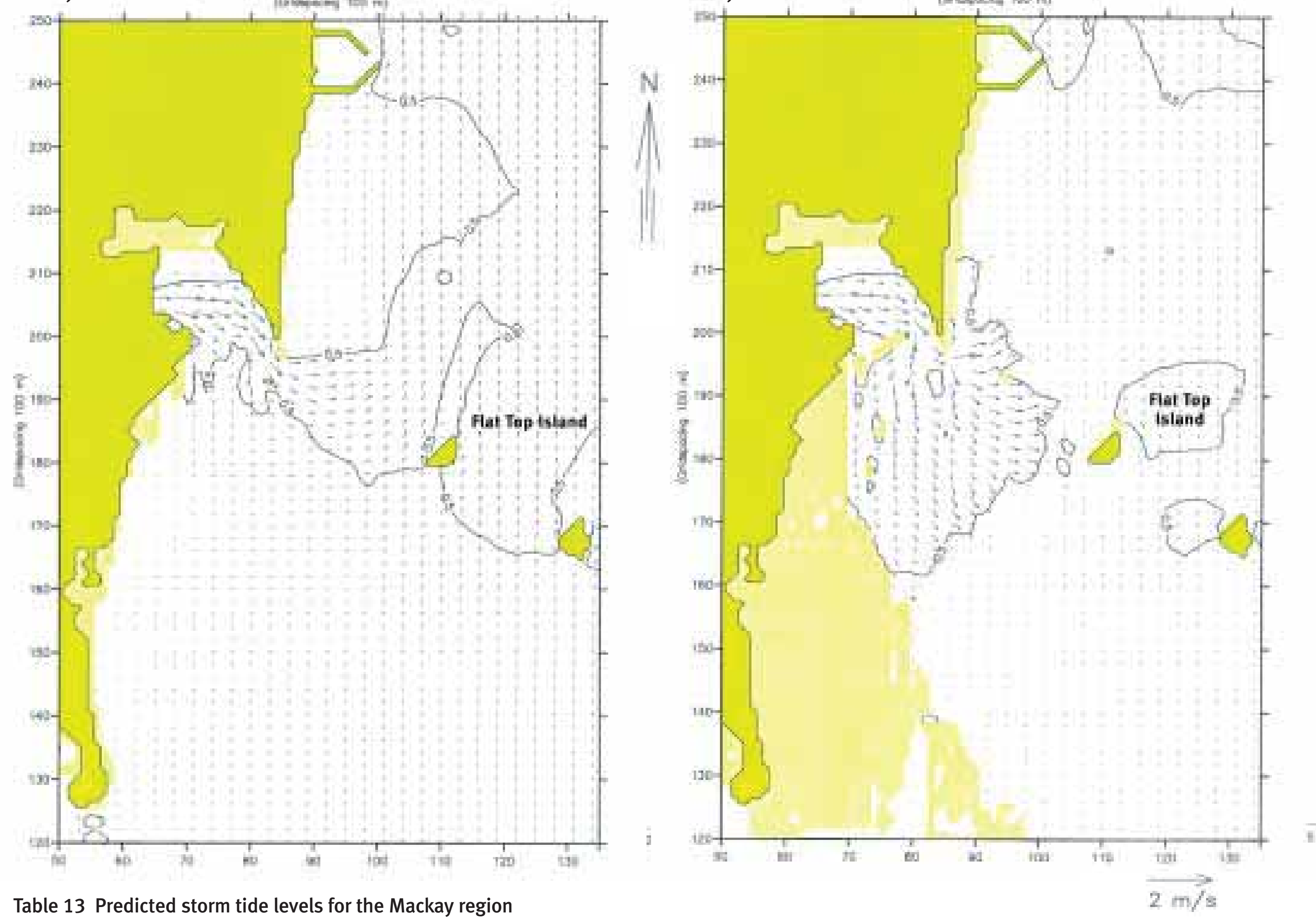


Table 13 Predicted storm tide levels for the Mackay region

Site	Storm tide relative to AHD 50yr (m)	100yr (m)	500yr (m)	1000yr (m)	10,000yr (m)	Wave set-up (m)
Hay Point	3.9	4.2	4.9	5.2	6.2	0.3
Mackay	3.8	4.1	4.9	5.2	6.2	0.5
Slade Point	3.7	4.1	4.8	5.1	6.1	0.5
Shoal Point	3.7	4.0	4.7	5.0	6.0	0.5

During the period from November through to May, Mackay is vulnerable to the effects of severe tropical cyclones, which are capable of inducing storm surges of up to five metres in magnitude. While the high tidal range provides some protection from inundation, numerical and statistical studies show that Mackay's risk of exceeding normal tide levels is amongst the highest of any section of the Queensland coast (Harper 1998).

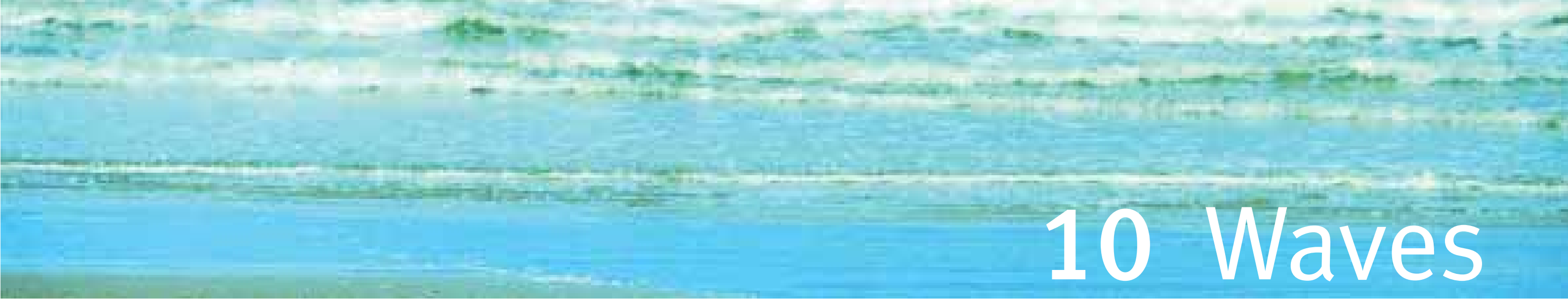
In January 1918, Mackay was the site of one of the most significant storm surges ever seen in Australia. The events surrounding that day have been summarised by Gourlay and Hacker (1986). A severe tropical cyclone with a central pressure of approximately 935hPa crossed the coast just north of the settlement and generated a storm surge of approximately 3.7m. This combined with the tide at the time to produce a storm tide level of 5.4m AHD, extensively flooding Mackay by up to two metres above HAT. This event is estimated to have an average recurrence interval of approximately 500 years. Several ships moored at the wharves were sunk, disabled or washed ashore. The northern half of the Sydney Street bridge was washed away after a ship had been driven against its downstream side by the storm tide. Two days after the storm tide impact, the extensive rainfall generated by the cyclone had produced a flood in the Pioneer River, which apparently reached levels similar to that of the storm tide.

In recent years the ackay region has not been subject to any serious storm tide threats. In 1956, tropical cyclone Agnes caused a 1.4m surge, and when tropical cyclone Althea crossed the coast near Townsville in 1971, Mackay registered a 0.9m surge. In March 1997, tropical cyclone Justin was centred some 500km offshore and generated a storm surge of almost 0.8m. As this event coincided with spring tides, maximum water levels exceeded HAT by a small margin.

In 1985 the Beach Protection Authority commissioned Blain, Bremner and Williams to complete a study of the joint probability aspects of surge and tide in the Mackay region (BPA 1985). This was based partly on the earlier numerical hydrodynamic modelling investigations by Sobey et al. (1977) and Harper et al. (1977). These early studies provided depth-integrated numerical hydrodynamic model results for a series of nine design cyclones (three tracks each of three different intensities) located to cause peak surge conditions at or near Mackay. The model was based on a five-nautical mile resolution and included the shape of the coast, the undersea bathymetry and the Great Barrier Reef, but did not consider tidal effects.

The BPA (1985) study extended the 1977 work by using the numerical model predictions within a statistical simulation model. This allowed the predicted surge from a cyclone of any intensity to be combined with a randomly generated astronomical tide to determine the total storm tide level. The statistics of cyclone characteristics were also developed for all cyclones within a region 300 nautical miles north–south and 150 nautical miles offshore for the period 1939 to 1980. An average frequency of occurrence of 0.76years between cyclones entering that region was derived.

These results were then assessed in terms of the probability of exceedance of storm tide levels at a number of sites (table 13) for a range of return periods. Separate values for peak wave set-up values were also included in the report recommendations (table 13).



10 Waves

Introduction

Wave effects are a critical component of the regional coastal processes. Wave action and wave-induced currents in the nearshore zone are generally the principal mechanisms of sediment transport and coastal erosion.

The Mackay region is afforded some protection against Coral Sea wave energy by the Great Barrier Reef. However, the outer reef formations extend more than 100km to the east at this latitude and create a relatively wide continental shelf with a south-easterly fetch in the order of 500km. This feature, when considered with the dominant south-easterly wind direction, provides the mechanism for significant localised wave generation (figure 23 illustrates the fetches relevant to the Mackay wave climate).

Locally generated wind waves, referred to as *sea*, are the most important component of the wave climate in the region. The swell component, waves generated from distant sources, is of less importance. The Capricorn Channel is the major opening in the Reef through which swell propagates into the area.

A detailed assessment of the wave climate of the region has been undertaken. Studies have included:

- an analysis of recorded wave data;
- estimation of the long-term, directional wave climate through hindcasting; and
- numerical modelling of wave transformation processes to determine wave climate information at inshore locations.

Wave recording

Wave recording has been undertaken for the Beach Protection Authority in the Mackay region since 1975. A near-continuous series of wave data is available for the station located near Bailey Islet, approximately 30km offshore from Mackay, from September 1975 (figure 19 shows the position of wave recording sites in the region).

In the period 1988 to 1990, wave data was recorded for a number of inshore sites. These sites have different exposures to wave conditions compared to the Mackay station due to the sheltering effects of adjacent headlands and the wave transformation effects of the offshore bathymetry (table 14 lists the active recording periods of the various stations).

Table 14 Recording periods, Mackay wave buoys

Buoy	Period
Mackay	19/9/1975 – present
Harbour Beach	11/3/1986 – 7/4/1987
Blacks Beach	12/5/1987 – 6/5/1988
Bucasia Beach	19/5/1988 – 11/5/1989
Far Beach	6/2/1990 – 18/2/1991

The standard wave recording and analysis procedure is described in the wave data summary report for the Mackay region (DEH 1998). Recorded data are analysed and archived in the form of wave spectra and a number of standard sea state parameters. Parameters include:

- significant wave height (Hsig), the average of the highest one-third waves in a record; and
- peak spectral period (Tp), the wave period corresponding to the peak of the wave spectrum.

Where both sea and swell waves coexist, the wave spectra tend to have a distinctive multi-modal shape. Analysis of wave spectra was undertaken to assess the relative contribution of sea and swell components to the total wave climate. This analysis was based on a procedure that examines the shape of the spectra to determine the 'split' frequency. Typical swell wave components are less than 0.5m therefore it was concluded that swell can be excluded from the overall wave climate.

The Mackay wave recording station has been operated primarily as a non-directional system. In April 1995 the equipment was upgraded to enable directional wave recording. Data analysis is similar to analysis of the non-directional wave data but it also provides directional spectra. The standard sea-state parameter that describes wave direction is the mean direction corresponding to the peak of the spectrum. The directional wave data, combined with a wave hindcasting study, enable a directional wave climate for the region to be estimated.

Wave hindcasting

Hindcasting is the prediction of historical wave conditions from recorded wind data. The 22 years of recorded wave data have been supplemented with a hindcasting study to determine a long-term average directional wind wave climate. This has provided:

- a more reliable long-term average by extending the data record back to 1957, a total of almost 40 years;
- wave direction information; and
- filling in of gaps in the recorded wave data.

The wave hindcasting was based on wind data recorded at three locations by the Bureau of Meteorology: Mackay (Mount Bassett), Creal Reef (150km north-east of Mackay) and Gannet Cay (350km east-south-east of Mackay). The wind data input was a composite from the three sites, verified against a short-term recording station established on Bailey Islet for the Beach Protection Authority.

Wind wave predictions were computed using SEARAY, the simplified fetch-limited spectral wave growth model developed by Walker (1989). This required the establishment of a radial grid centred on the Mackay wave recording site near Bailey Islet. Measured wave data has been used to verify the operation of the model and other supporting assumptions, as well as supplanting modelled data for the periods when measurements were unavailable (figure 24 summarises the wave climate for the region over the period 1960 to 1996 derived from recorded data and the wave hindcasting). The majority of all waves come from the east-south-east and south-east sectors, with significant wave heights less than 1.0m and a period of three to seven seconds.

Figure 23 Fetch directions, Mackay waves

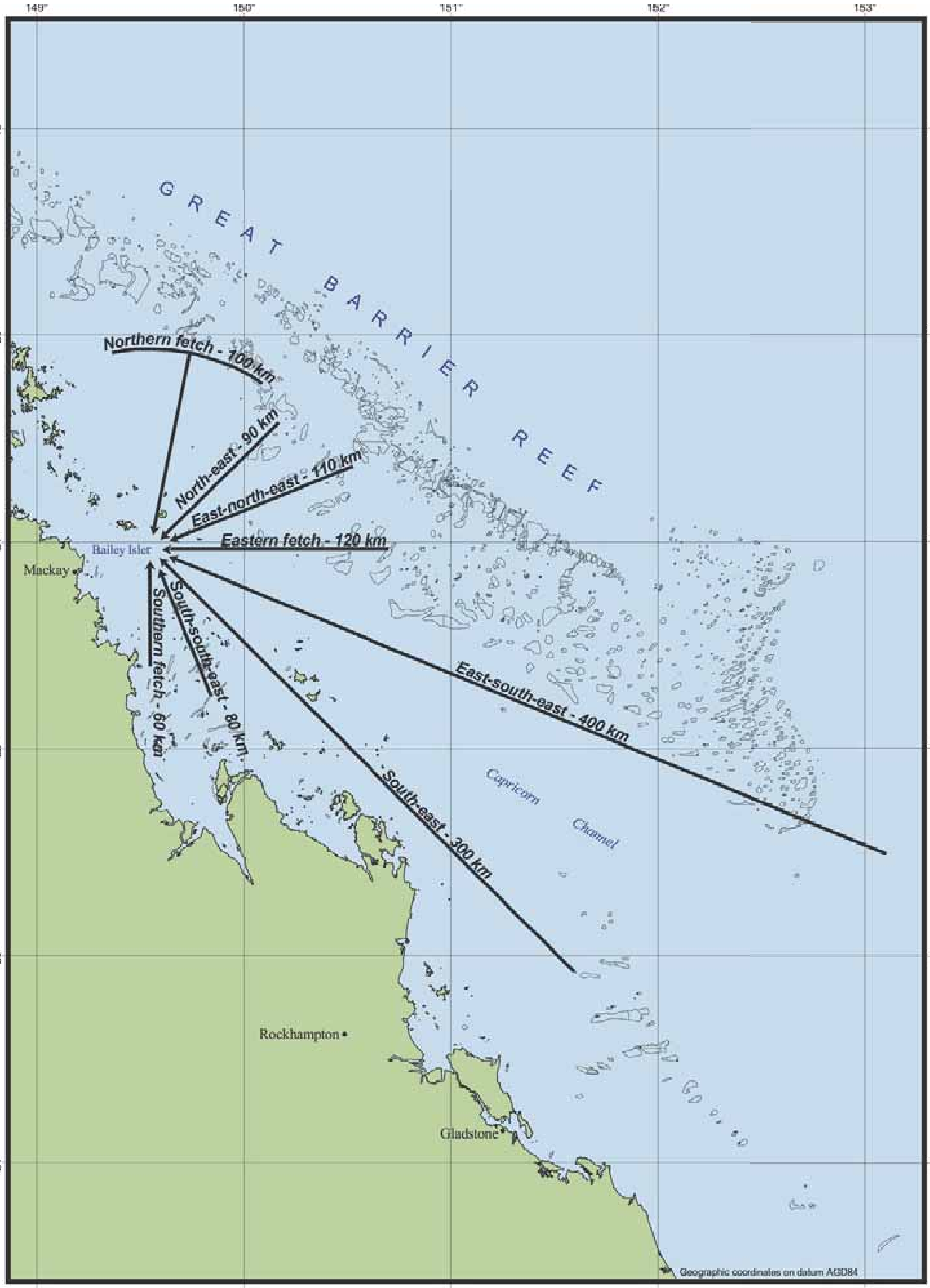
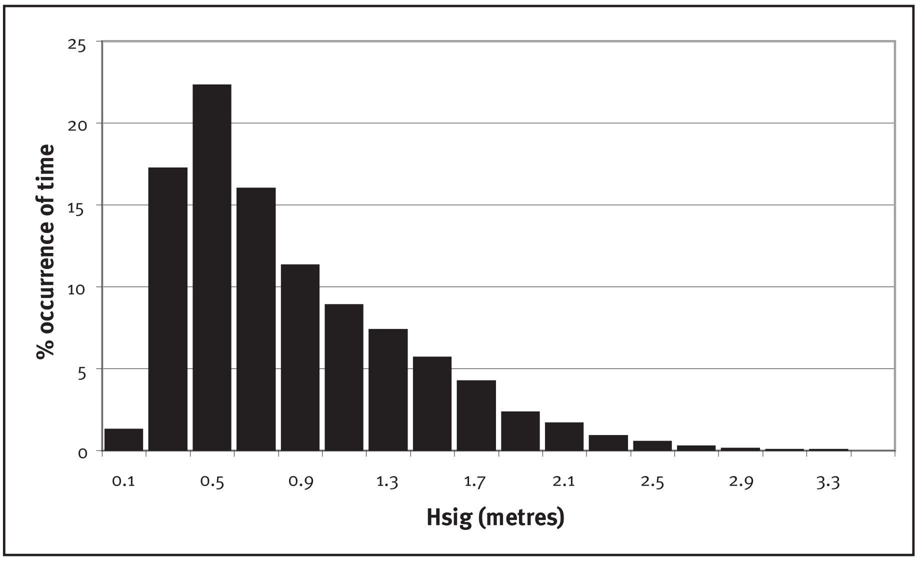
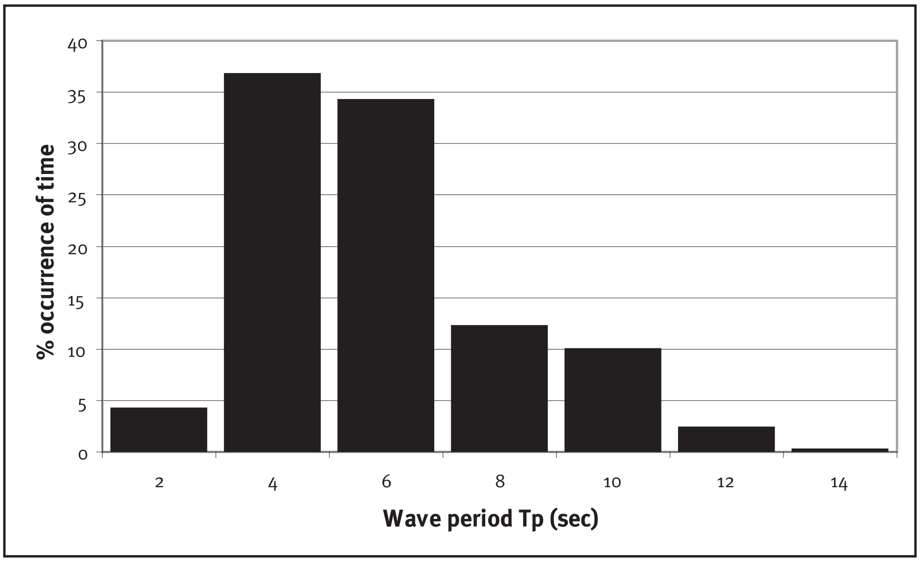
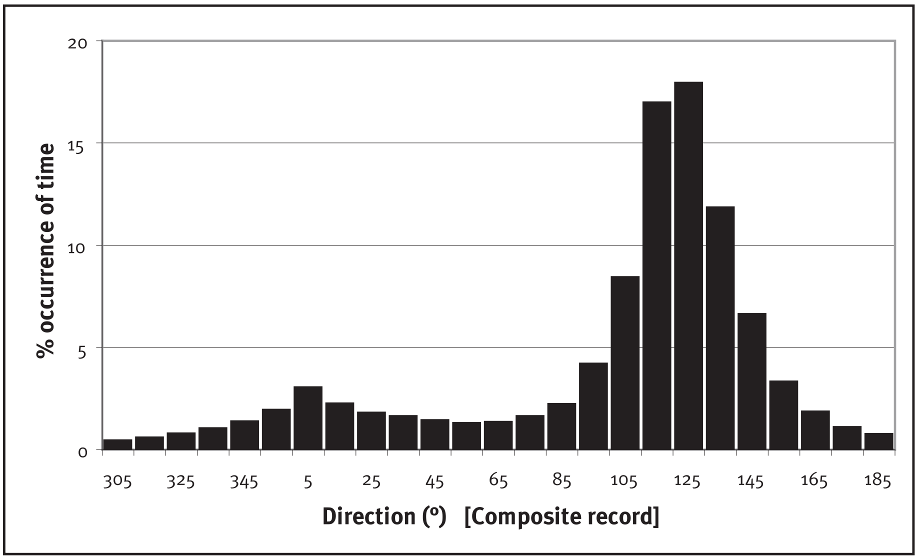


Figure 24 Percentage occurrence of wave height and period (1975 to 1996; from DEH 1998) and wave direction from composite wave record (1960 to 1996)







Inshore wave conditions

Waves propagating from deeper water to inshore areas of the Mackay region undergo a transformation process influenced mainly by the change in water depth. This is also affected by the high tidal range and strong tidal currents in the region.

The MIKE 21 Nearshore Spectral Wave modelling system was used to describe the propagation, growth and decay of short-period and short-crested waves from the offshore area to the shore. By using a finite difference technique, the model accounts for the effects of wave refraction, shoaling, bottom friction and wave breaking (DHI 1998).

A wave model for the region was constructed over three grids corresponding to the major directional sectors of south-east, east and north-east. The bathymetry in each grid was digitised at a resolution of 500m by 125m. Data from the inshore wave recording stations were used to verify the operation of the model. More than 1,300 model runs were undertaken to construct inshore directional wave climates for four locations. Wave climate information was described with a resolution of 0.5m wave height, two seconds wave period and 10° wave direction.

Additional model runs were undertaken to assess the effects of the tidal elevation and tidal currents on the propagation of waves across the region. The tests indicated that the wave-current interaction and tide range have little overall effect on the nearshore wave climate. The maximum observed effect on wave height was in the order of seven percent, but when the approximately equal probability of ebb and flood conditions is considered, the overall bias is negligible (figure 25 summarises the inshore directional wave climate data determined from the modelling).

Extreme events

Extreme wave events can have a major impact on the Mackay coastal region. Severe wave conditions are often associated with tropical cyclones, although Coral Sea low pressure systems and, to a lesser extent, trade wind *surges* also cause high wave conditions.

An analysis was conducted on the Bailey Islet recorded wave data, supplemented with hindcast information, to develop estimates of extreme wave statistics. A set of 58 peak storm wave heights was derived from the available data over the period September 1975 to December 1997.

Synoptic records were reviewed for all the identified storms in order to classify events into common types. The dominant storm category is the tropical low pressure system, which includes tropical cyclones, Coral Sea lows and ex-cyclones. These systems have the potential to generate sustained periods of onshore gale force winds and are often enhanced by the effects of adjacent areas of high pressure lying to the south of the region. A number of lower energy storms (10 out of 58) were attributed to trade wind events.

An analysis of the inter-arrival times of the set of identified storms has shown that there is a high likelihood (almost 50 percent) that an event will be followed by another within 60 days. This clustering of events is important in the assessment of beach erosion due to the cumulative effects of severe storm wave conditions.

Estimates of extreme wave statistics have been calculated from the set of peak storm wave height data following the method recommended by Goda (1988). Only storm events attributed to tropical cyclones and tropical lows were considered. Data for the trade wind storm type were excluded from the analysis, primarily because of the limited potential of this type to generate extreme wave conditions.

The calculation of extreme wave statistics has enabled estimates to be made of extrapolated values of storm wave heights for a range of return intervals (table 15). It is noted that the highest peak wave height in the data set for tropical cyclone Justin (March 1997) corresponds to an average return interval of approximately 32 years. This is notable since Justin did not cross the coast near Mackay. Peak wave conditions (three hourly average Hsig of 4.74m) occurred when the system was centred approximately 500km offshore.

Figure 25 Inshore directional wave climate

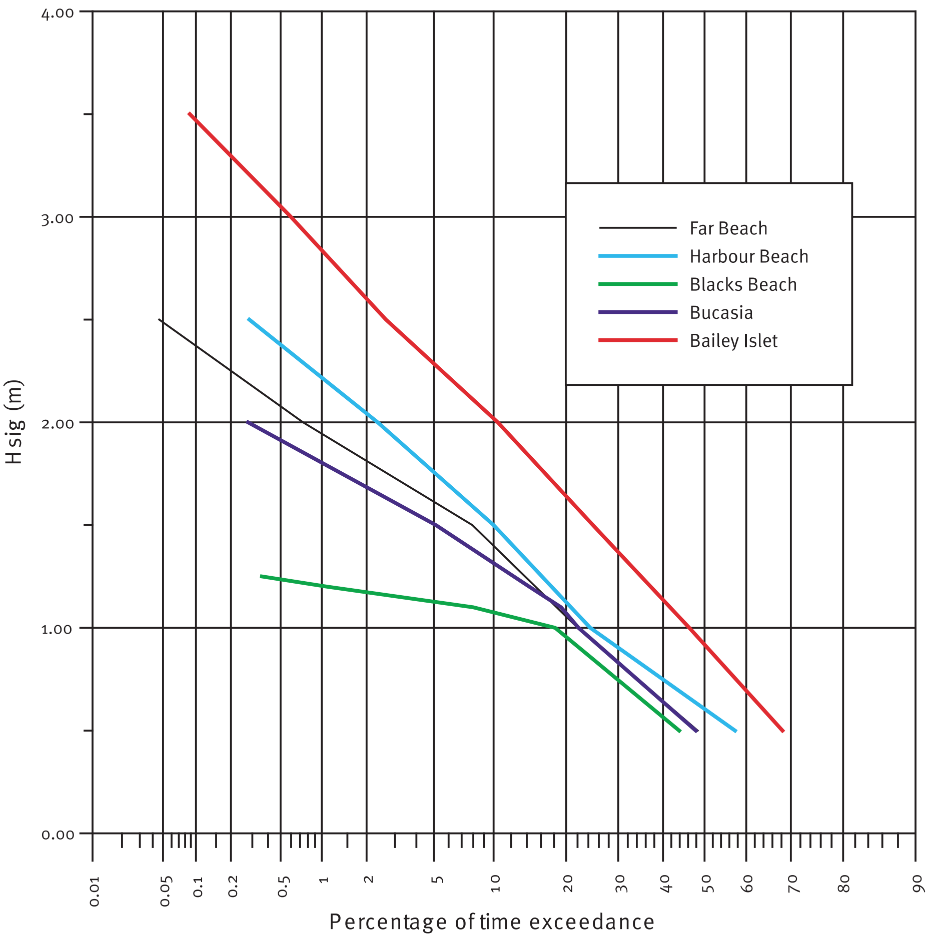
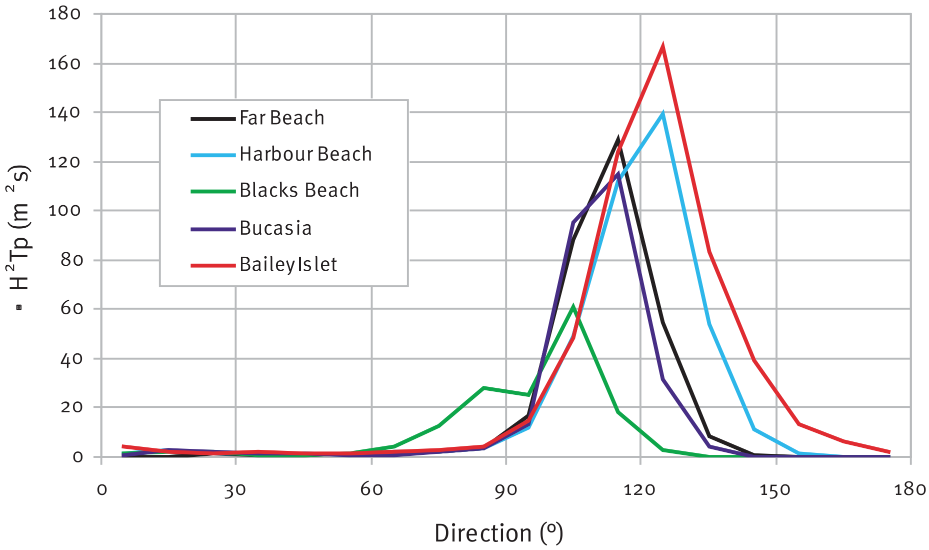


Figure 26 Comparison of inshore and offshore directional wave energy



The historical record indicates a significant natural variability in the occurrence of severe storm events. Much of this variability is associated with the correlation of tropical cyclone activity with the Southern Oscillation.

The negative phase of the Southern Oscillation generally coincides with cooler surface temperatures in the Coral Sea and tends to promote the persistence of westerly winds aloft, leading to a reduced number of tropical cyclones in the region.

It is apparent that the period of available wave recordings has coincided with a generally negative trend in the Southern Oscillation Index (figure 14) and a relatively quiet period in tropical cyclone activity along the east coast of Queensland. It is considered, therefore, that the calculated statistics probably underestimate the potential extreme values over the longer term.

The direction of storm waves can have an important bearing on the overall effects on coastal processes. Estimates of wave direction at the time of the storm peak have been determined from the wave hindcasting and the recorded directional wave spectra (figure 27) indicating a strong bias to the east to south-easterly sector. This is largely due to the restricted fetches for all other directional sectors.

Joint probability of waves and water levels

The overall effect of high wave conditions on coastal processes is highly dependent on the water level. For example, a severe storm coinciding with neap tide conditions would have less impact on beaches than a more moderate event in conjunction with a large spring tide. In the Mackay region, consideration of the large tide range is critical in evaluating the impacts of extreme events.

The probabilities of waves and water levels are not independent due to the common forcing of extreme waves and storm surges by tropical cyclones and other severe events. Numerical simulation of the two effects in conjunction is required to correctly estimate joint probabilities.

A storm tide risk assessment study was undertaken at nearby Hay Point (BBW 1984) and included some limited spectral wave modelling. The wave model results were then combined with the storm tide results to assess the joint probability of wave height and storm tide level. The study also included Mackay as a reference point (figure 28 summarises these results in terms of the likelihood of experiencing a given significant wave height at the same time as a given storm tide level. For example, there is a 45 percent chance of not exceeding a five metre wave height at or above the 100-year return period storm tide level and only a 30 percent chance at the 500-year return period level).

At the lower end of the range, extreme wave estimates from the BBW study correspond closely with the values derived from the recorded data (table 15). The extreme value associated with the 50-year return period is estimated as a height of 5m (compared with 4.9m given in table 15), the 100-year value being 5.4m (compared with 5.2m in table 15). The extreme wave height associated with a 1000-year return period is estimated as 7m.

Figure 27 Directional distribution of extreme waves

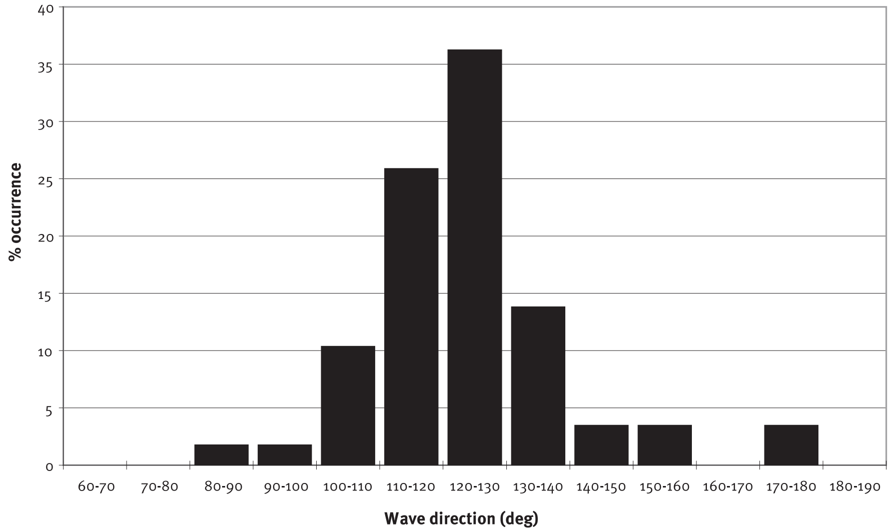


Figure 28 Predicted return period of tropical cyclone wave heights in the Mackay region

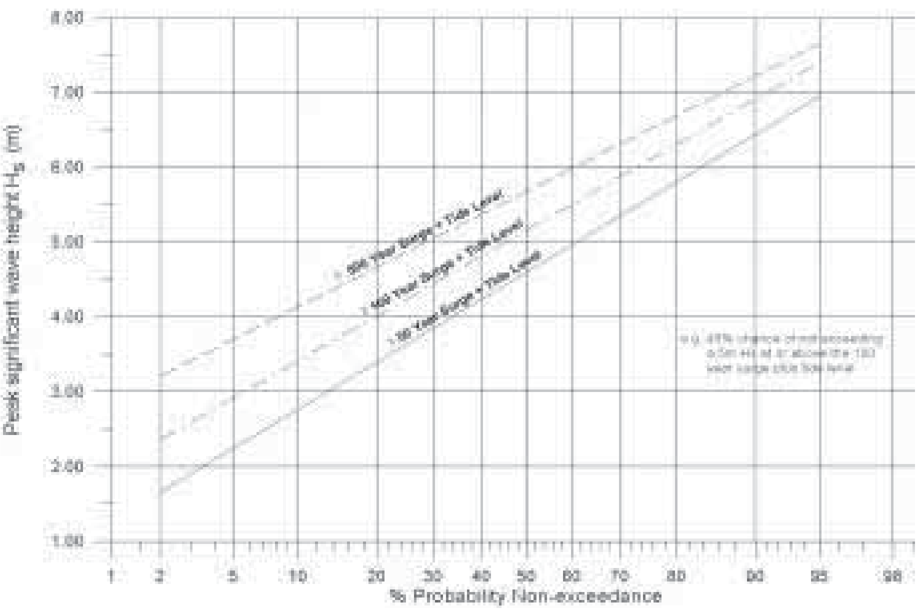


Table 15 Storm wave heights for selected return intervals

Average return interval (years)	Hsig (m)
2	3.4
10	4.2
50	4.9
100	5.2

11 Surf zone processes

Introduction

A large proportion of coastal sediment transport throughout the Mackay region occurs in the surf zone. In order to make reasonable estimates of sediment transport rates, it is therefore necessary to accurately quantify the key surf zone processes.

Waves propagating into shallow water undergo a number of transformation processes caused by the influence of the seabed. The wave face becomes steeper and reduces in forward speed and the oscillatory motion becomes more asymmetric. This process continues as the depth decreases until the wave form becomes unstable and breaks. Broken waves continue across the surf zone before finally dissipating in the swash zone. Important processes to consider include:

- the onshore flow, or mass transport of water;
- a corresponding return flow directed offshore that may be in the form of a relatively weak diffuse flow and/or channelled into rip currents;
- the generation of oscillatory currents at the seabed;
- a local increase in water level, known as wave set-up; and
- the generation of a steady state longshore current by waves approaching the shoreline at an angle.

The wave-induced longshore currents interact with the nearshore tidal currents and are overlain with the orbital current field of each individual wave. The net cross-shore currents generated by the balance between onshore wave-driven flows and return flows also interact with tidal currents, particularly on the wide intertidal areas. The shallow water wave processes are complex and difficult to describe comprehensively. The large tidal range and strong nearshore tidal currents in the Mackay region add to the complexity.

Only limited field data of surf zone hydrodynamics in the Mackay region are available. These data include COPE (Coastal Observation Programme — Engineering) observations of nearshore waves and currents and a short-term current metering campaign undertaken for the Beach Protection Authority in 1992.

Blacks Beach and COPE Station in the foreground. COPE data provided valuable verification of numerical models.

The data show longshore current velocities of up to 1m/s and the strong influence of nearshore tidal flows.

Numerical modelling

Quantifying surf zone processes has been undertaken using the Unibest CL+ (version 5.01) numerical modelling system developed by Delft Hydraulics (1999). The Unibest model computes the wave and current distribution across an arbitrary beach profile, taking as input the wave and current conditions at the seaward end of the line. Using linear wave theory, empirical formulae and energy balance considerations, the model determines:

- wave decay through the surf zone;
- wave set-up;
- wave-induced steady state longshore currents; and
- the near-bed orbital currents.

A number of assumptions are present in the model formulation; these include the use of linear wave theory in the surf zone and the assumption of straight and parallel nearshore depth contours. Additionally, Unibest CL+ does not consider cross-shore flows. Despite these limitations, this approach is considered to be sufficiently accurate for the present study in estimating longshore sediment transport rates.

The model computes longshore currents across a profile from the balance between wave radiation stresses and friction. The friction component is dependent on oscillatory and steady state velocities. The intensity and distribution of the modelled wave-induced longshore currents is dependent on wave characteristics and the bottom roughness (k_b). The choice of values for this parameter is critical in the representation of longshore currents and, therefore, sediment transport in the model. The value adopted for the parameter k_b was 0.25. This choice provided the closest agreement between the model and field data.

Table 16 Relative probability of tidal conditions

Condition	WL (m)	% occurrence
slack	0.00	24
neap flood	–1.00	24
spring flood	–2.22	13
neap ebb	1.12	26
spring ebb	2.34	13

Table 17 Longshore tidal current speeds and depths used in Unibest model

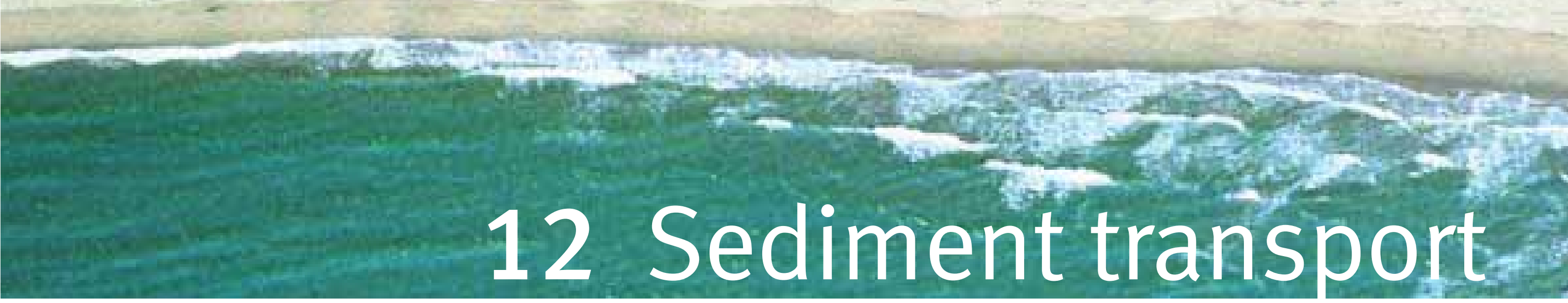
Beach	Spring ebb (m/s)	Neap ebb (m/s)	Neap flood (m/s)	Spring flood (m/s)	Depth (m AHD)
Far/Town	–0.30	–0.13	0.13	0.18	11.2
Harbour (S)	–0.47	–0.20	0.24	0.38	14.3
Harbour (N)	–0.56	–0.26	0.29	0.47	14.8
Blacks	–0.31	–0.18	0.16	0.22	7.5
Bucasia	–0.36	–0.18	0.19	0.30	11.2

The strong effects of the tide in the region influenced the selection of boundary conditions for the Unibest CL+ model. Five tidal conditions were used, corresponding to flood/ebb and neap/spring combinations along with a slack water case. The relative probability of each case was derived from the water level probability density function and an assessment of tidal flow data (table 16).

Wave climate and tidal current data were extracted from the numerical models (for tidal current details see table 17).

The surf zone processes at Mackay are complicated by topography, bathymetry and the large tidal range. The Unibest CL+ model is one-dimensional and does not consider the two-dimensional effects of tidal flats and offshore shoals. The wide tidal flats south of the Pioneer River mean that the surf zone can extend as far as 4km from the dunes at low tide. The bays in the lee of headlands pose a similar problem, to a lesser extent.

The shoals at Blacks Beach reduce the wave height reaching the beach. The combination of the sheltering effects of Slade Point and the nearshore shoals leads to complex surf zone processes at Blacks Beach.



12 Sediment transport

Introduction

Understanding of coastal sediment transport is an important component in coastal zone management. Sediment flows shape the system of dunes, beaches and offshore banks that are crucial for coastal protection and beach amenity. Estimates of longshore sediment transport rates within the study area are required for an assessment of the overall sedimentation regime and can provide an insight into potential long-term changes in the shoreline position and sediment budget.

Sediment transport in the Mackay coastal region is driven primarily by the action of waves and tidal flows. In general, waves from the predominant south-easterly sector and the dominant northward-setting ebb tidal stream combine to drive sediment in a generally northerly direction through the study area.

The large tidal range of the region has an important bearing on sediment transport patterns due to the variation of water level at the shoreline as well as the generation of tidal currents. Both steady state and oscillatory flows play important roles in sediment dynamics, and the two interact with each other via the wave and current boundary layers. It is therefore critical that the two are considered together, even though waves and tidal currents are generated by independent processes.

Longshore transport modelling

A number of empirical and semi-empirical sediment transport formulae have been developed for use in coastal applications. The commonly used formula of van Rijn (1989) is appropriate for use in the Mackay region as it considers the processes of entrainment, transportation and deposition under the action of waves and steady currents.

The application of this formula in this study was primarily through the Delft Hydraulics software system Unibest CL+ (version 5.01). Unibest CL+ is a one-dimensional modelling system only. It combines a model of nearshore hydrodynamics and the sediment transport model to determine longshore sediment transport perpendicular to a fixed profile.

A major assumption in this approach is that the local coastal section is treated as prismatic: that is, the local nearshore depth contours are assumed to be straight and parallel. This assumption is acceptable over relatively long and continuous coastal sections, but it does not allow detailed study of two-dimensional sediment transport around complex topography (as in the lee of headlands).

Estimates of net sediment flows were averaged over time periods considerably longer than individual tidal cycles or storm events. This provided estimates of long-term average net sediment transport rates due to the wave climate and the tidal current climate associated with the astronomical tide. Nearshore wave and current conditions are input into Unibest in the form of a climate, each condition being assigned a relative duration. The model integrates the results from each condition to determine the total average sediment transport rate.

The sediment transport formula of van Rijn uses D50 and D90 parameters to represent the sediment size. The values adopted for this study are derived from average COPE measurements of sediment size and are shown, along with their corresponding fall velocities, in table 18. The density of the sediment was taken as 2650kg/m^3. Jones (1987) conducted an extensive sediment survey further offshore (sample locations are seen in figure 29). This study classified sediment units by the mean grain size and the degree of sorting (figure 30).

The Unibest CL+ model assumes the sediment size is constant across the profile, but analyses of sediment samples show there is some variation in sediment sizes across most profiles.

Table 18 Sediment sizes used in longshore transport model

Beach	D_{50} μm	D_{90} μm	ws (m/s)
Far Beach	700	1000	0.079
Harbour Beach	500	950	0.059
Lamberts Beach	550	1000	0.065
Blacks Beach	350	750	0.040
Bucasia Beach	350	750	0.040

This was taken into account in the model calibration process (values adopted for other sediment and wave parameters are shown in table 19).

Figure 30 Mean grain size versus sorting for sandy sediment units (from Jones 1987)

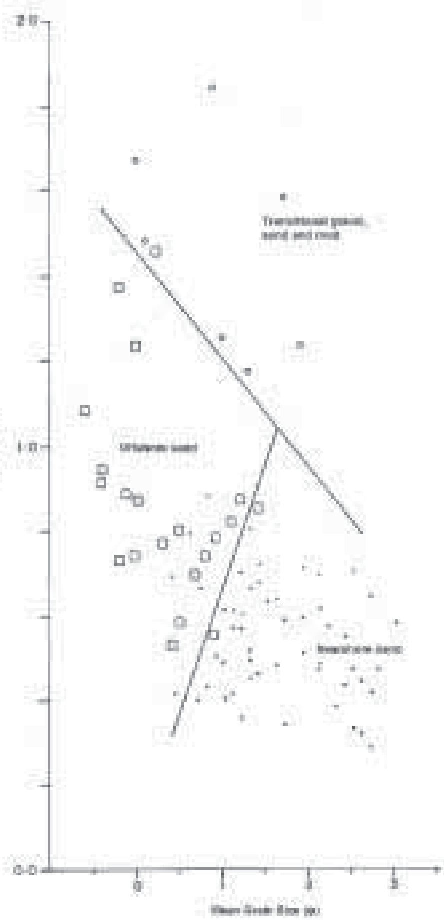


Table 19 Values of sediment and wave parameters used in sediment transport modelling

Parameter	Symbol	Value
Wave breaking constant	α_c	1
Wave breaking parameter	γ_2	0.7
Wave bed friction coefficient	f_w	0.01
Bottom roughness (m)	k_b	0.25
Current bottom roughness (m)	r_c	0.10
Wave bottom roughness (m)	r_w	0.10
Seawater viscosity (m^2/s^2)	υ	1.0 x 10^{-6}
Porosity	p	0.40
Reference height ratio	a/h	0.01

Figure 29 Extent of sediment sampling by Jones (1987)

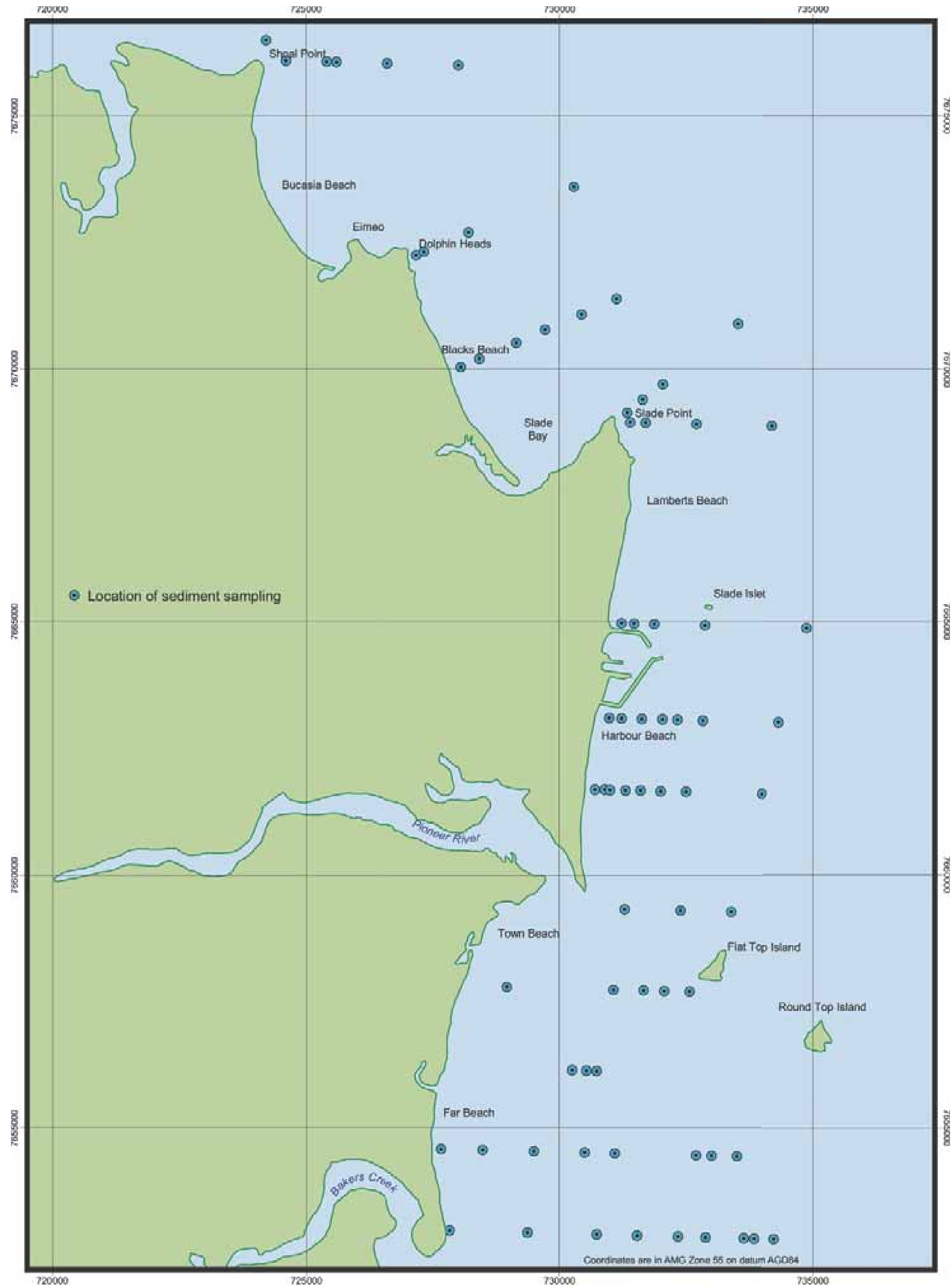


Table 20 Predicted longshore transport rates

Beach	Survey profile	Longshore transport rate (m^3/a^1)
Town/Far	MAC108	–
Harbour (S)	MAC124	35 900
Harbour (N)	MAC134	32 900
Blacks	MAC159	28 000
Bucasia	MAC179	20 200

Table 20 provides the summary output from the model for the four locations. The results show a net average transport rate along Harbour Beach south of about 36,000m^3/a moving northwards. Volumetric analysis of survey data at Harbour Beach, taking into account the documented sand extraction rates in this area, has been used to verify the modelled transport rate. This model was then applied throughout the study area.

Figure 31 shows the distribution of longshore sediment transport across the profile at Harbour Beach south. The results show that sediment transport is negligible beyond a point approximately 500m offshore.

The longshore sediment transport rates have been derived from long-term average wave and tidal current conditions. Analysis of the calculated rates at Harbour Beach shows that 50 percent of the total longshore sediment transport occurs when the offshore wave conditions exceed a threshold in the order of 1.7m. This value represents an annual exceedance of five percent, therefore it is clear that a large proportion of longshore sediment transport at Mackay occurs episodically during higher wave energy events. The overall sedimentation patterns are therefore sensitive to variations in the wave climate.

The transport rate reduces further north from the Pioneer River:

- on Harbour Beach north the rate is reduced slightly due to the change in the coastline orientation compared to Harbour Beach south; and
- at the northern end of Blacks Beach, the estimated rate is reduced again. The difference is in the order of 5000m^3/a and is attributed to the rate of supply to the nearshore shoals.

Cross-shore sediment transport

The short-term erosion of beaches in response to storm wave conditions is well known and is an important consideration in coastal management planning. An equally important response is the shoreward transport of sediment during moderate wave conditions to rebuild the upper beach and dunes.

The prediction of sediment transport across a beach profile is relatively more complex than the prediction of longshore transport rates. In general, the net rate and direction of cross-shore sediment transport are the result of a balance between several mechanisms including:

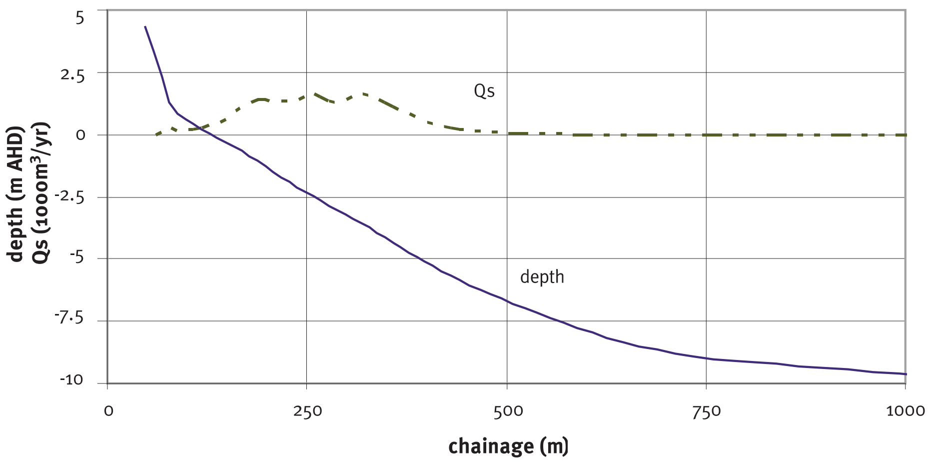
- onshore movement driven by the asymmetry of wave orbital currents in the surf zone;
- the offshore-directed return flow;
- the effects of bound long waves;
- currents generated by the incoming and outgoing tides; and
- aeolian (wind-driven) transport of sand driven onshore by the predominantly south-easterly winds acting over dry sections of the beach.

The macrotidal environment accentuates the latter two mechanisms, particularly over the areas of wide intertidal flats.

Numerical models of cross-shore sediment transport processes generally fall into two categories, according to the characteristic time scale used to resolve sediment motion (Larson 1996). Microscale models attempt to describe the processes under individual waves and overall results are gained by integrating over time. Mesoscale models simulate the time-averaged processes, which are the result of many waves. Typically, mesoscale models are more reliable in describing broadscale beach profile changes, such as short-term erosion in response to storm events. These models are less successful in simulating onshore sediment transport and details such as the formation of nearshore bars.

No attempt has been made to undertake generalised numerical simulation of cross-shore transport rates as part of this study. Modelling of short-term storm erosion using the SBEACH model has been used as part of the review of erosion prone areas. This is described in the discussion of short-term erosion. Some information on cross-shore sediment transport has been inferred from survey data and analysis of aerial photography. This was primarily used for the assessment of movement of shoals in Slade Bay.

Figure 31 Cross–shore distribution of longshore sediment transport at Harbour Beach



13 Coastal topography

Introduction

The coastal topography in the study area comprises a number of complex features that reflect the interaction of the underlying geological formations with the continuing fluvial and coastal processes.

Topographic information has been compiled from a number of sources including:

- existing navigation charts and topographic maps;
- beach profile survey data; and
- aerial photography.

Beach profiles were surveyed over 60 Beach Protection Authority standard lines by the Department of Transport (previously Department of Harbours and Marine) through the region in 1971, 1977, 1978, 1979, 1981, 1986, 1992 and 1997 (figure 32 shows the location of all survey lines in the study region).

Low-level aerial photography (at scale 1:12,000) was captured for the Beach Protection Authority in the Mackay region in May to June 1974, August 1977, November 1978, July 1981, June 1985, June 1991, June 1993 and October to November 1997. Aerial photography before 1974 was undertaken at various scales and coverages; most notable are the 1947 to 1948 data, captured at scales of 1:30,000 and 1:32,000.

QASCO Surveys Pty Ltd was commissioned to undertake a photogrammetric study of the region to provide topographic information on the nearshore and shoreline areas based on the June 1993 photography. Additionally, a comparison of historical shorelines (represented by the Highest Astronomical Tide contour) was made for the 1947 to 1948 and May to June 1974 photography. A pre-1900 shoreline was also constructed from historical field surveys to provide a qualitative view of coastline changes.

Offshore bathymetry

The continental shelf in the region is relatively wide and slopes gently to the 100m isobath, located approximately 200km offshore. Depths are less than 30m in most parts. The bathymetry is relatively complex, with numerous islands and shoal patches, notably Blackwood Shoals to the north-east and Viscount Shoals to the south-east.

The Great Barrier Reef is located 100 to 120km offshore of Mackay. A significant opening (the Capricorn Channel) lies to the south-east of the region. The configuration of the reef and the continental shelf offshore from Mackay have a significant influence on the hydrodynamics of the region.

Dudgeon Point and Hay Point lie to the south of the study area. These headlands, forming the lower section of Sandringham Bay, have a significant coastal control over the southern section of the Mackay region.

Topographic features

The main topographic features of the region, along with representative beach profiles, is summarised in figure 33. The profile across Far Beach (MAC108) is typical of the coastal section south of the Pioneer River entrance. The beach is characterised by wide tidal flats backed by a low frontal dune system. The tidal flats are significant, with a very flat gradient extending out to more than 2.5km offshore. The elevation of the tidal flats typically slopes from approximately mean sea-level to mean low water level at the seaward edge.

The dunes in this section are often quite low, having a typical height of 5 to 7m AHD. Behind the dunes are a number of small, back-barrier creek systems that drain across the tidal flats. From behind the dunes, the topography slopes gently landward through South Mackay and East Mackay. These areas are relatively low-lying, with typical elevations of 4.5 to 5m AHD.

The topography around the Pioneer River entrance shows a distinct delta formation with significant subtidal features extending out towards Flat Top Island. The coastal alignment is offset by approximately 800m either side of the river (figure 34). This section of coastline has shown the most change over recent history, reflecting the high fluvial input of sediments from the Pioneer River to the coastal system.

The Harbour Beach profile (MAC122; figure 33) shows a distinct difference from the Far Beach profile, having a much narrower intertidal area and a higher dune system. The dunes increase in height from south to north along this section, rising to more than 20m AHD near Slade Point. Some dune areas have been levelled for residential and port purposes, mainly around the central section of the beach.

Behind the dunes are areas of low-lying freshwater and tidal wetlands, most notably Bassett Basin. The coastal alignment is controlled by the significant rock outcrop of Slade Point and, to a lesser extent, the Mackay Harbour walls. Other rock outcrops are evident including Slade Islet, Dangerous Reef and the small rock outcrop that separates Harbour Beach from Lamberts Beach.

The beach profiles in this section generally show a monotonically-increasing, concave-upward slope and comprise two distinct parts: a relatively flat intertidal zone extending from below the mean water level and a steep, reflective upper beach.

Figure 32 Location of survey lines

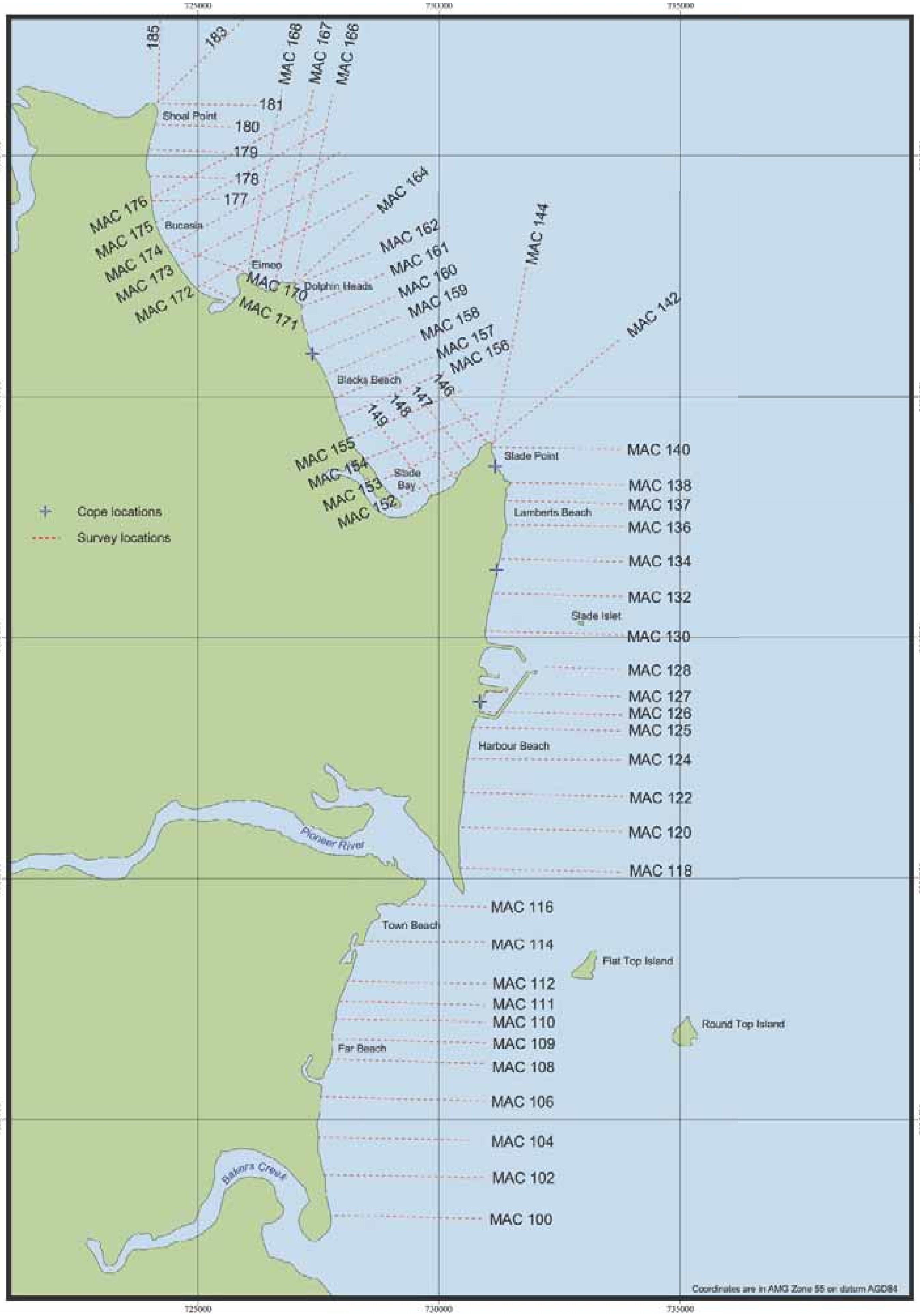


Figure 33 Representative beach profiles

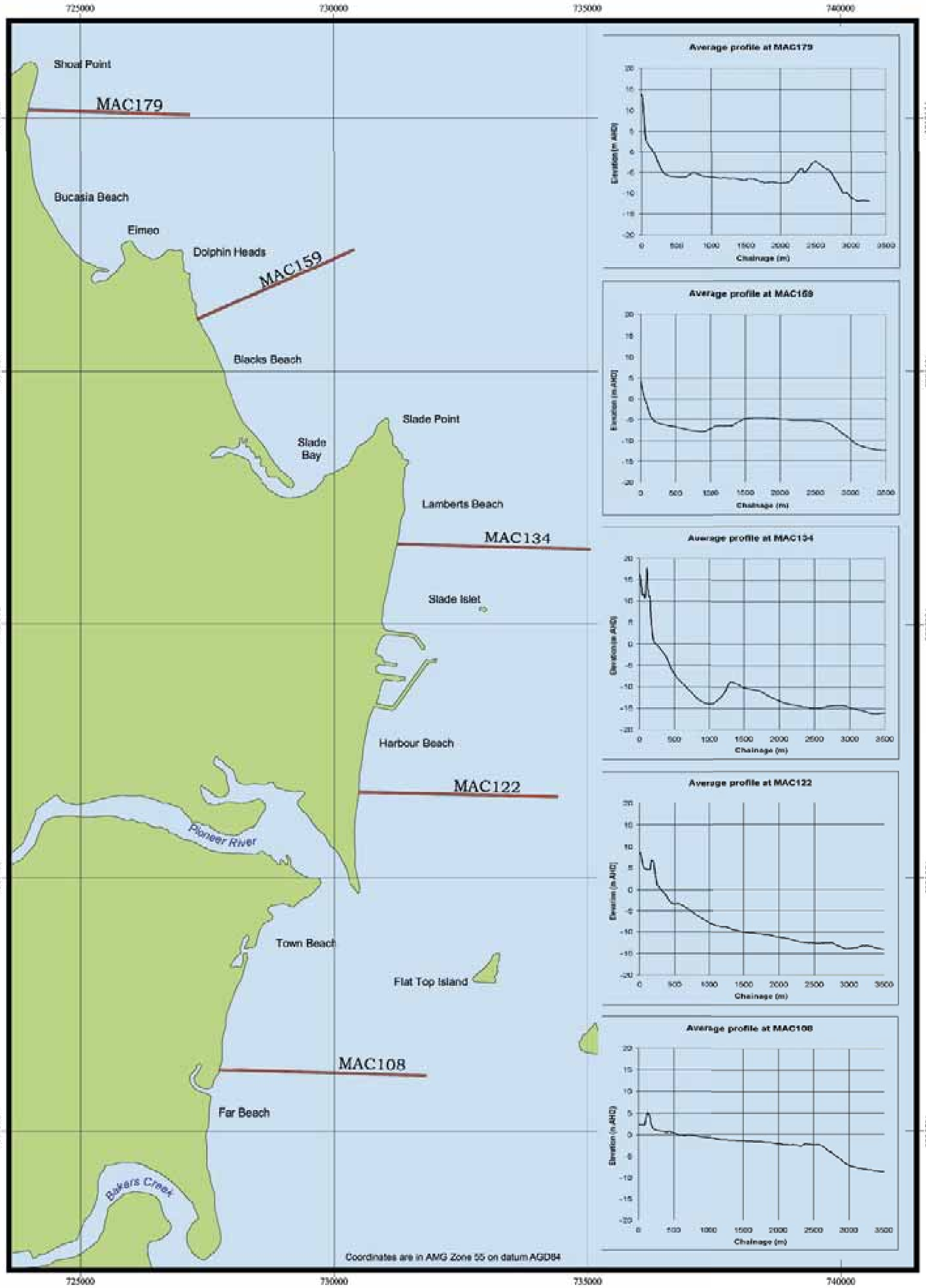


Figure 34 Pioneer River entrance (17/8/93)

Figure 35 Slade Bay (14/8/93)

North of Slade Point, the embayments of Slade Bay and Sunset Bay have formed between rocky headlands. These two sections are topographically quite similar. Common features include:

- wide intertidal areas formed from the deposition of sediments in the lee of headlands (figure 35);
- beach barrier systems backed by low dunes and tidal wetlands;
- shallow estuaries of McCreadys Creek and Eimeo Creek draining into the southern corner of the embayments; and
- narrowing beaches at the northern end of the embayments backed by rocky cliffs.

The Blacks Beach profile (MAC159; figure 33) is typical of the northern end of Blacks Beach and shows a significant sandy shoal approximately 200m offshore. The beach shows a concave-upward morphology similar to that of Harbour Beach, although the inshore gradient is steeper and the dunes are markedly lower.

Bucasia Beach (MAC179; figure 33) is backed by high dunes in the order of 10 to 15m AHD. Rock outcrops are present approximately 2.5km offshore. All other topographic aspects of the beach are otherwise very similar to Blacks Beach.

14 Geological history

Introduction

A study of the geological evolution of the region provides an understanding of the present-day configuration of the Mackay coast and an insight into the continuing coastal processes.

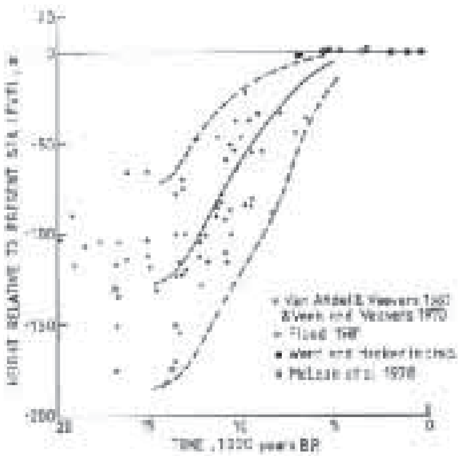
The period of geological history of most relevance is the Quaternary period, which extends from about 1.8 million years BP and comprises the Pleistocene epoch (1.8 million to 10,000 years BP) and the Holocene epoch (from 10,000 years BP to present).

A number of background studies of the geological history of the region are available, including studies commissioned by the Beach Protection Authority. In addition, Gourlay and Hacker (1986) provide a detailed description of the sedimentation processes in the Pioneer River and include a discussion of the geomorphology of the river and the adjacent coastal areas. More recently, Masselink and Lessa (1995) provided a discussion of the geomorphology of the Bucasia area.

Mean sea-level

Over geological timescales, shoreline erosion and deposition processes are closely linked to variations in mean sea-level. During the Quaternary period, global sea-levels have varied considerably in response to variations in the extent of the polar ice fields. During the last glaciation, about 18,000 years BP, water levels were approximately 120m below present levels and the shoreline was beyond the present location of the Great Barrier Reef. Post-glacial sea-level rise, known as the marine transgression, began about 15,000 to 12,000 years BP and reached present levels about 6500 years BP (mean sea-levels over the past 20,000 years are schematically shown in figure 36).

Figure 36 Sea-level rise over the last 20 000 years (Gourlay and Hacker 1986)



Sea-level changes over the later Holocene tended to vary across the region due to local isostatic movements in response to the water load on the continental shelf. Stephens (1993) concludes that the peak of the transgression (approximately 1m above the present mean sea-level) occurred about 5000 to 4000 years BP in the Proserpine region, then gradually fell to reach the relatively constant modern level about 3000 to 1000 years ago. Gourlay and Hacker (1986) reported no evidence of higher sea-levels around Mackay.

Masselink and Lessa (1995) discuss the possibility that a wave climate and tidal range different from those of the present may have existed in the region during the period of sea-level rise leading up to the peak of the marine transgression. Due to the rapid average sea-level rise of 13mm/a, the growth of the Great Barrier Reef may have significantly lagged behind the water level. The effects of the reef in providing shelter from Pacific Ocean wave energy and amplification of the tide would also have lagged, therefore creating a tide and wave window. Masselink and Lessa contend that wave energy reaching the shoreline during this period may have been higher than present day conditions.

Pre-Holocene geology

Extensive outcrops of bedrock are seen along the coast and the offshore islands. This rock is part of the Palaeozoic Campwyn Beds in the south and the Tertiary Cape Hillsborough Beds in the north. Notable bedrock features along the coast include Dudgeon Point, Slade Point, Dolphin Heads and Shoal Point. These features have had a strong influence on the formation of the modern-day shoreline. Other prominent features include Mount Bassett, Flat Top Island, Round Top Island and Slade Islet. Mount Bassett is an intrusion of a more recent Cretaceous microdiorite formation.

The upper parts of the Pioneer River catchment are dominated by the mountainous terrain of Connor Range. This range is composed of igneous granitic formations known as the Urannah Complex, which are more recent than the Campwyn Beds. These rocks are important in that they are relatively prone to erosion and they decompose to sand rather than silts. It is likely that an extensive eroded surface underlies the alluvium in the vicinity of the present coastline. The present-day coastal sediments are derived predominantly from material eroded from the Pioneer River catchment.

The late Pleistocene land surface consolidated during the last glacial sea-level low. Throughout the region, sequences of Pleistocene age alluvial sands and clays overlie the bedrock, and near the coast they are mostly covered by the more recent Holocene deposition. The Pleistocene sequences can be seen behind the back barrier wetlands (figure 37).

North of the Pioneer River a number of relict beach ridge formations of Pleistocene age have been identified, notably in the Andergrove area. South of the Pioneer River, the Pleistocene clay surface is seen approximately 300m behind the shoreline, rising gradually landward. A relict Pleistocene deposit intersecting the coastline has been identified in the vicinity of Dolphin Heads (figure 37).

Holocene deposition

The deposition of sediments during the Holocene has resulted in the formation of the present coastline. Once sea-level rise slowed to the present trend approximately 6500 years BP, the coastline began to develop towards equilibrium with the new continental shelf and wave climate. Onshore transport of sand and other sediments from the offshore continental slope, which included submerged river flood plains and deltas, contributed to the progradation of beaches during the early Holocene.

Sediments are derived from two main sources: the pre-existing sand deposits driven landward during the marine transgression and the more recent fluvial deposits from the Pioneer River. Analysis of the surficial sediments (Jones 1987) indicates that the Pioneer River is the most significant modern-day supplier of sediments to the Mackay coast.

South of the Pioneer River the median grain size of sediments in the nearshore zone is in the order of 0.7mm. The grain size varies moving north from the Pioneer River. At Harbour Beach the median grain size is typically 0.55mm, while at Blacks Beach and Bucasia the values reduce to 0.35mm.

A delineation of two major marine sediment types can be made using grain size analysis. The finer-grained sediments with relatively low carbonate content (primarily shell fragments) are found on the beaches and in the nearshore zone to a depth of approximately –10m AHD. These deposits are attributed to the recent supply from the Pioneer River. The relict sand deposits transported shoreward during the marine transgression are identified as coarser-grained sediments with higher carbonate content; these are found further offshore (the zone of delineation between the two major marine sediment types is seen in figure 37).

The present-day shoreline configuration is largely controlled by the major bedrock outcrop features of Dudgeon Point, Slade Point, Dolphin Heads and Shoal Point. These structures are relatively erosion-resistant and have formed control points for the adjacent beach systems (a schematic distribution of the historical geology in the region is seen in figure 37).

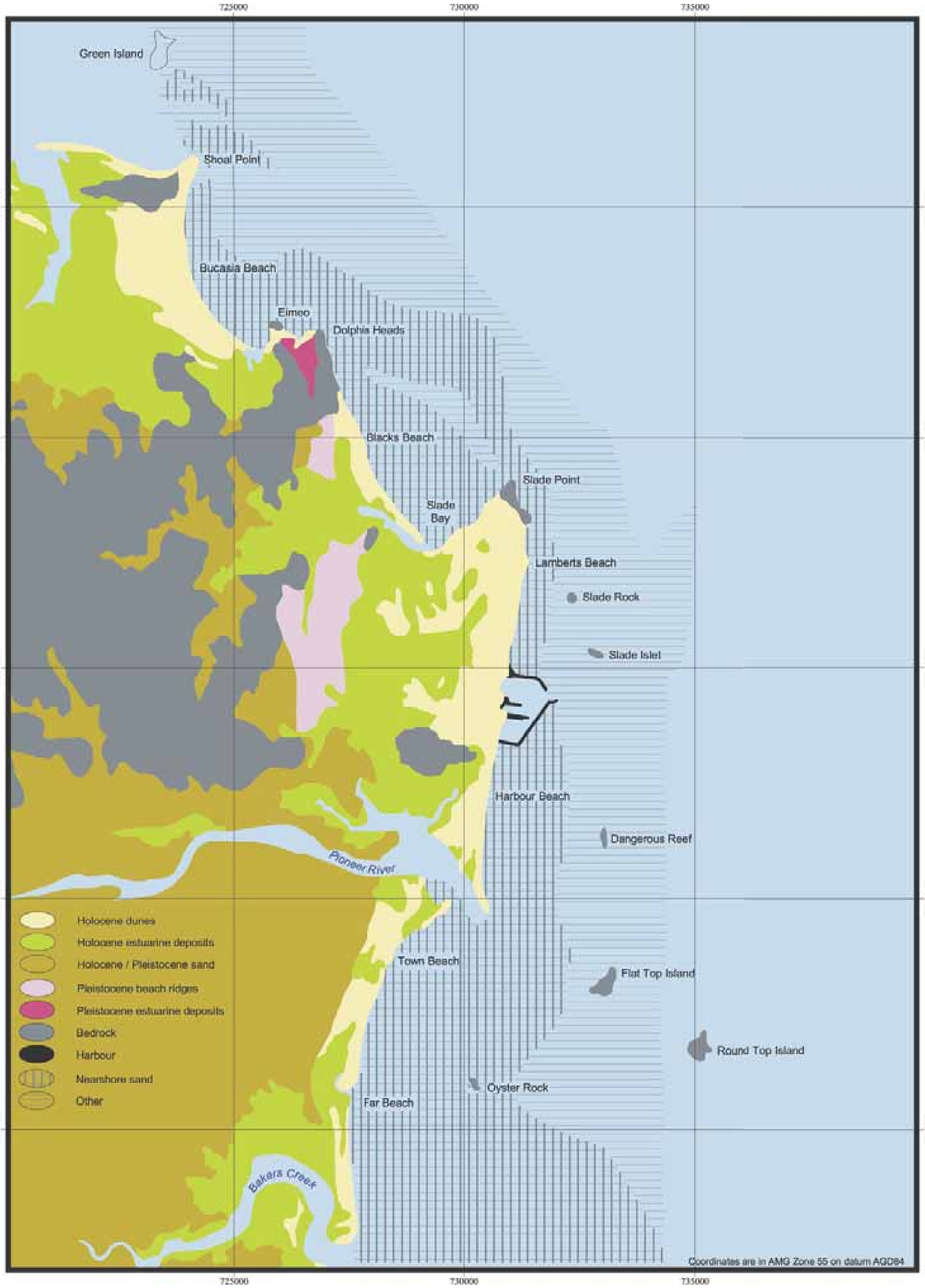
Gourlay and Hacker (1986) describe the relatively recent changes to the course and catchment of the Pioneer River. Until comparatively recent times the course of the lower Pioneer River followed the present paths of Sandy Creek and then Bakers Creek, cutting through the Pleistocene coastal plain.

The evidence suggests that the upper catchment was not as large as its present configuration, resulting in lower rates of fluvial supply of sediments to the coast at that time.

At an estimated 3500 years BP, the Pioneer River was redirected to its present location and, due to changes in the upper catchment, now carries a significantly higher sediment load. The development of the Pioneer River estuary and the adjacent coast into their present-day forms began at this time.

Far Beach and Town Beach showing the complex coastal features of the Pioneer River entrance.

Figure 37 Geological history of Mackay region



The mechanism of sandy barrier morphology is described by Masselink and Lessa (1995). As the outer ridges developed in response to rising sea-levels, the areas behind them became sheltered, allowing fine sediments to accumulate to form the extensive tidal and freshwater wetland areas north of the Pioneer River. The height and extent of the barrier formation is strongly related to sediment supply. The extensive deposits of the dune fields immediately north of the river entrance can be attributed to the large rate of sediment supply to the coast from the Pioneer River.

Jones (1987) theorised that during the interval between 6500 and 3500 years BP a large delta formed in Sandringham Bay to the south of Mackay. This delta has since eroded and been reworked to its present configuration, and has supplied significant volumes of sand to the tidal flats and the beaches to the north. Due to the comparatively lower rate of fluvial supply from the previous courses of the Pioneer River, the dune systems of Far Beach and Town Beach are lower in height and width than those of Harbour Beach. The mechanism of barrier formation was similar to that of the beaches north of the river, resulting in low-lying areas behind the beach ridge of similar, but less developed morphology.

Calculation of the average annual supply of sand to the northern beaches has been attempted, using radiocarbon dating from borehole samples. A total sand supply to the beaches in the order of 25 000m^3/a over the past few thousand years has been estimated. It is also likely that a considerable volume of sand has bypassed the delta and beaches to be deposited further along the coast or offshore. The offshore seismic survey reported by Hegarty (1983) indicated a sedimentary lens of considerable thickness north-east of Green Island overlying the Pleistocene (clay) seismic basement. The strong tidal flows north of Slade Point and Shoal Point have acted to direct sediments to nearshore sandy shoal deposits.

Features identified in the offshore seismic profiling investigation reported by Hegarty (1983) included a series of inner continental-shelf shoal systems, including the Blackwood Shoals north-east of Shoal Point. The systems had varying morphology and seismic characteristics, and were interpreted by Jones (1987) as relict sand wave deposits developed during the marine transgression. Although they have a strong fluvial character, these sediments also contain indicators of the marine environment in which they now occur. Such indicators include a relatively high biogenic calcium carbonate content and the shaping of the deposits by tidal currents into sandbanks and sand waves.

The estimated sedimentary supply to the beaches and to deposits offshore from the study area during the Holocene totals 250million m^3, an annual volume of 40,000m^3. In addition, a considerable volume of sediment has been deposited in Sand Bay, north-west of Shoal Point. Jones (1987) concluded that the Pioneer River could not have provided all the sediment for the delta, beaches and these additional deposits. Some of the sediments in the offshore shoals may have been eroded from the Pleistocene surface or the abandoned delta during the marine transgression. It is therefore not possible to derive sediment transport rates from the geological evidence.

Shoal Point and Sand Bay.

15 Sediment supply and distribution

Introduction

An outline of the present-day sediment supply and distribution patterns of the Mackay coast can be inferred from the geological history of the region along with the analysis of recent data.

Data analysis undertaken for this study consists of:

- volumetric analysis of beach survey data including hydrographic surveys and profiles recorded for the Beach Protection Authority's COPE program spanning the period from 1971 to 1997;
- the comparison of historical shorelines by QASCO Surveys Pty Ltd using the 1947 to 1948, May to June 1974 and June 1993 photography and a pre-1900 shoreline constructed from historical field surveys;
- a photogrammetric study of the Pioneer River entrance using the available Beach Protection Authority aerial photography; and
- estimates of coastal longshore sediment transport fluxes based on analysis of wave conditions and tidal flows.

The work by Gourlay and Hacker (1986) on the Pioneer River estuary and the study of the impacts of sand and gravel extraction on the Pioneer River tidal reaches by Gutteridge Haskins and Davey Pty Ltd (GHD 1998) also provide further information on the local processes (a representation, not to scale, of the sediment supply and distribution throughout the study area is given in figure 38).

Pioneer River tidal reaches

Gourlay and Hacker (1986) conducted an extensive investigation of the Pioneer River, using the results from several physical model studies to determine the overall dynamics of the river and catchment system. One of the key findings of this study was that the Pioneer River is the major source of sediments forming the tidal flats and sandy beaches of the coast adjacent to the entrance.

Gourlay and Hacker describe how the hydrology of the region, along with the nature of the Pioneer River catchment and its geology, leads to a comparatively high fluvial sediment supply rate. Prior to the construction of the weirs, an average rate of sediment supply in the order of 200,000m^3/a was estimated; this includes both bed load and suspended load. More recent estimates of the average sediment yield from the Pioneer River catchment to the estuary have been made by GHD. Taking into account a range of factors including the trapping of sediments by upstream flow-control structures, estimates of the rate of supply of sand and gravel material to the Pioneer River estuary vary between 12,000m^3/a and 55,000m^3/a (GHD 1998).

An additional consideration is the effect of the weirs in reducing the maximum value of major flood discharges. For a given extreme rainfall event in the Pioneer River catchment, the magnitude of the peak discharge will be influenced by the storage effects of the weirs. Since the rate of sediment transport is proportional to the flow velocity raised to the power of approximately three, this has a potentially significant effect on the net fluvial supply rate to the coast.

The sedimentation patterns in the tidal reaches of the Pioneer River are complex and are complicated by anthropogenic effects such as flow-control structures and commercial sand and gravel extraction operations. The construction of weirs at Mirani, Marian and Dumbleton has led to impoundment of large volumes of the coarser bed material sediments, thus reducing the supply to the lower reaches.

Significant volumes of material have been extracted from within the tidal reaches of the Pioneer River and the adjacent coastal areas since settlement began. Much of this extraction is undocumented. GHD (1998) outline the rates of extraction from the various licensed sites from available records (figure 39 details the various extraction sites). Over the period 1976 to 1997, the average annual extraction rate under permits from the Mackay Port Authority and the Queensland Department of Environment and Heritage (now Environmental Protection Agency was approximately 88,000m^3/a. This does not include extraction operations on the coast.

Some sections of the tidal reaches show evidence of bank erosion due to continuing natural processes and/or associated with structures such as training works and bridges. There is also recent evidence of accretion in some sections, including an area in the vicinity of Cullen Island and in Bassett Basin. The gradual infill of Bassett Basin is a result of the reworking of lower estuary sediments by tidal flows and aeolian transport from Harbour Beach. This infill is partially artificial because the construction of the training wall on the northern bank of the river has limited the flushing of Bassett Basin by flooding.

Overall, it is highly probable that the tidal reaches of the Pioneer River are now experiencing a net loss of sediments due to the combined actions of flow-control structures, commercial extraction activities and natural processes. GHD (1998) recommended that the permitted rate of extraction within the tidal reaches of the river be reduced from 100,000m^3/a to a more sustainable rate of 22,000m^3/a.

Sand extraction operations in the Pioneer River.

Figure 38 Sediment supply and distribution

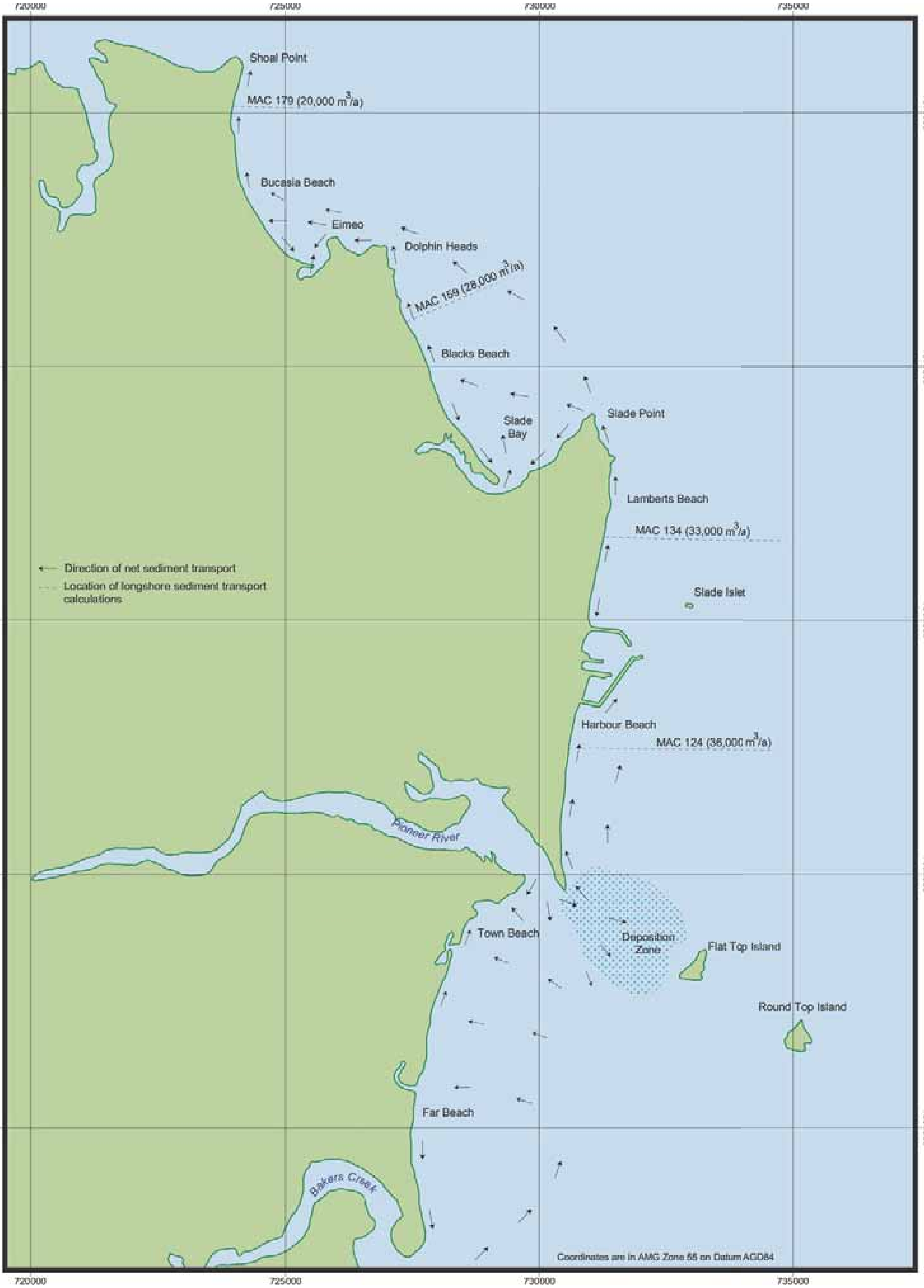
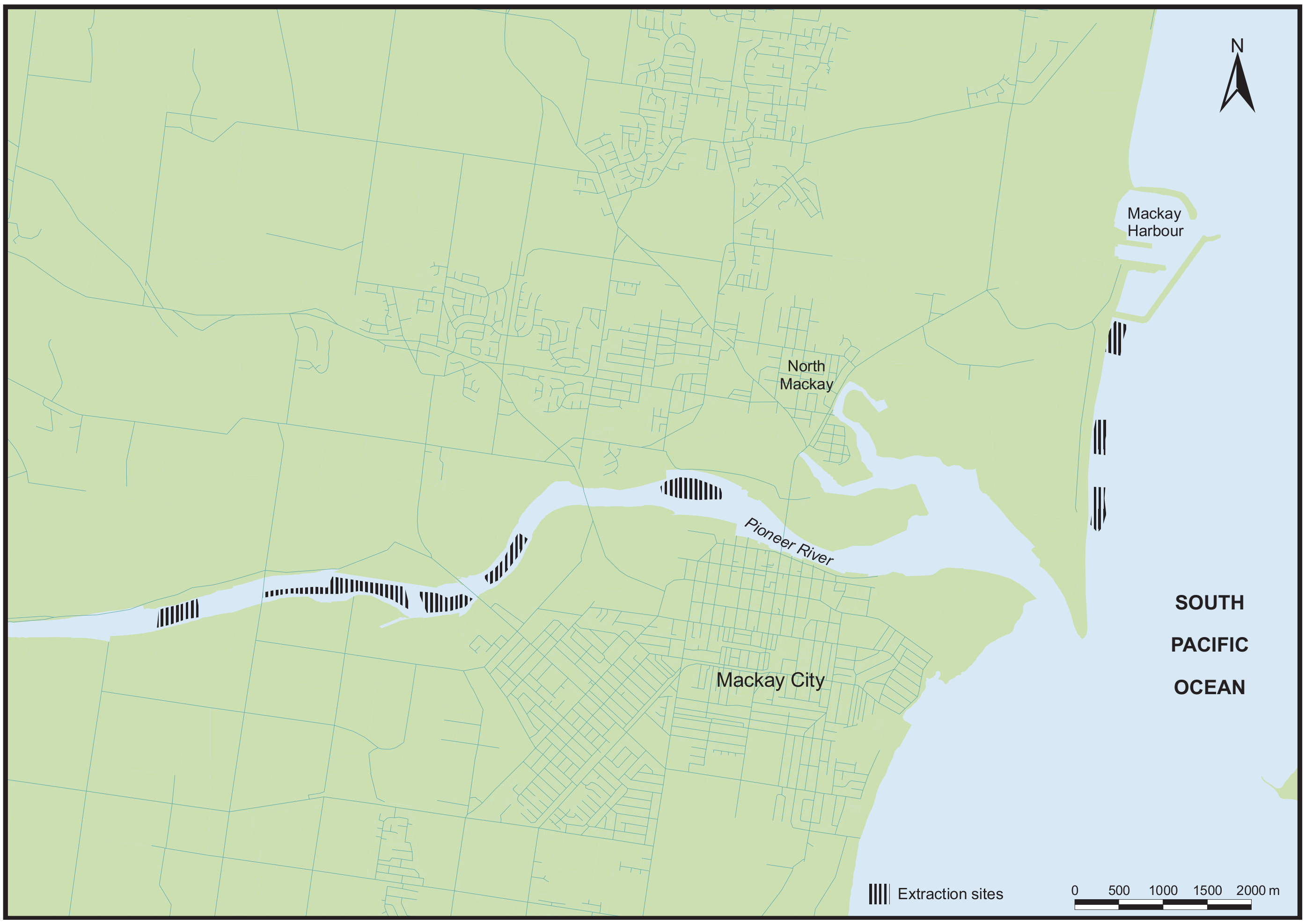


Figure 39 Location of sand and gravel extraction sites



Pioneer River entrance

The behaviour of the Pioneer River entrance has changed significantly since the construction of the training walls at the river mouth (figure 40). These works were originally constructed between 1887 and 1892, following recommendations of the eminent English harbour engineer Sir John Coode. The northern wall was modified to its present alignment shortly after the breakthrough of the northern spit in 1898.

Gourlay and Hacker (1986, p114) summarised the changes to the Pioneer River bar that occurred more than 100 years ago:

> 'In 1898, during cyclone Eline, the position of the mouth of the Pioneer River was altered dramatically when the river broke through the original elongated East Point. Before the cyclone occurred, the river flowed out to sea in a south-south-westerly direction parallel to the existing East Mackay foreshore. The original East Point was the southernmost tip of a long thin low spit extending two km south from the present East Point. It was about two m above high water level at its northern end and less than 0.5m above high water level further south. It would appear to have been formed from sand brought down by the river in times of flood and deposited on the bar seaward of the river mouth. This sand would then have subsequently moved by wave and wind action, both onshore and alongshore in a southerly direction, to form the spit.'

The mechanism for growth of the spit involved the transport of sediments to the bar by out-flowing currents associated with ebb tides and floods. The sediments were then reworked landward and into a bank structure by wave action. This resulted in an elongated spit that extended southward with a slight westward curve at its seaward end. Gourlay and Hacker reported that the river had broken through the spit several times before the 1898 event but had always reformed to approximately the same general configuration.

The preferred alignment for the main river entrance channel is presently towards the south-south-east. The extensive sand deposits no longer form a continuous spit structure and have the appearance of a subtidal delta. Only small sections are above the 0m AHD level, and one or more minor secondary channels periodically form close to East Point on generally east to north-easterly alignments. These secondary channels are associated with ebb tidal flows. The peak ebb tidal flow occurs close to high water and the near-field flow is directed generally northward. The preferred ebb tide discharge from the estuary is therefore across the delta towards the north-east.

The changes to the overall sedimentation pattern of the entrance area can be attributed to the effects of the training walls. The northern training wall armours the inside of the river bank and limits the supply of sediment to the area immediately downstream of the wall's end. This results in a terminal effect – the characteristic erosion of an unprotected coastline adjacent to a hard structure which tends to promote the formation of the secondary channel running eastward from East Point and limits the vertical growth of the spit. The southern training wall acts to deflect the outgoing flow eastward and reinforces the general tendency to deposit sediments in the area south-east from the river mouth. The sedimentation patterns are also influenced by the frequency and intensity of flood and storm events, and the impacts of sand extraction.

Figure 40 Aerial photograph, Town Beach to Harbour Beach south

Figure 41 Growth of Pioneer River tidal delta, 1962–97

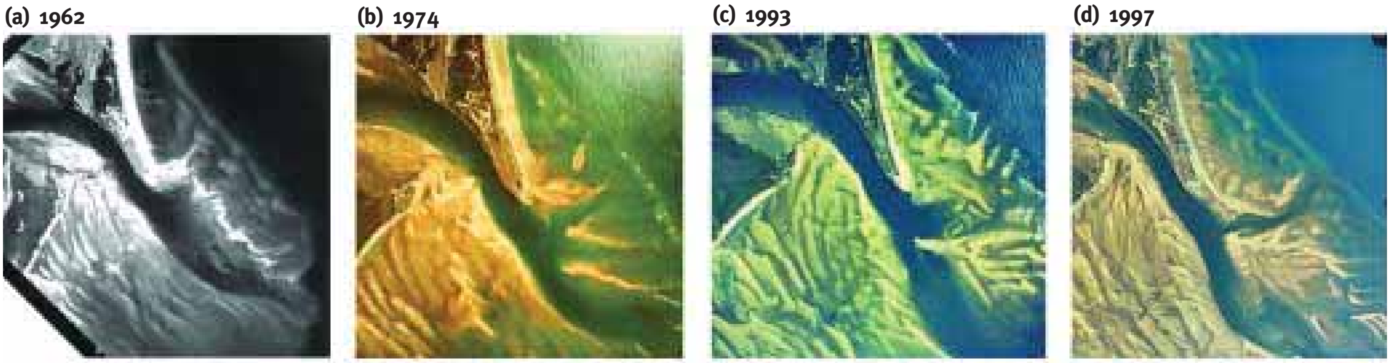
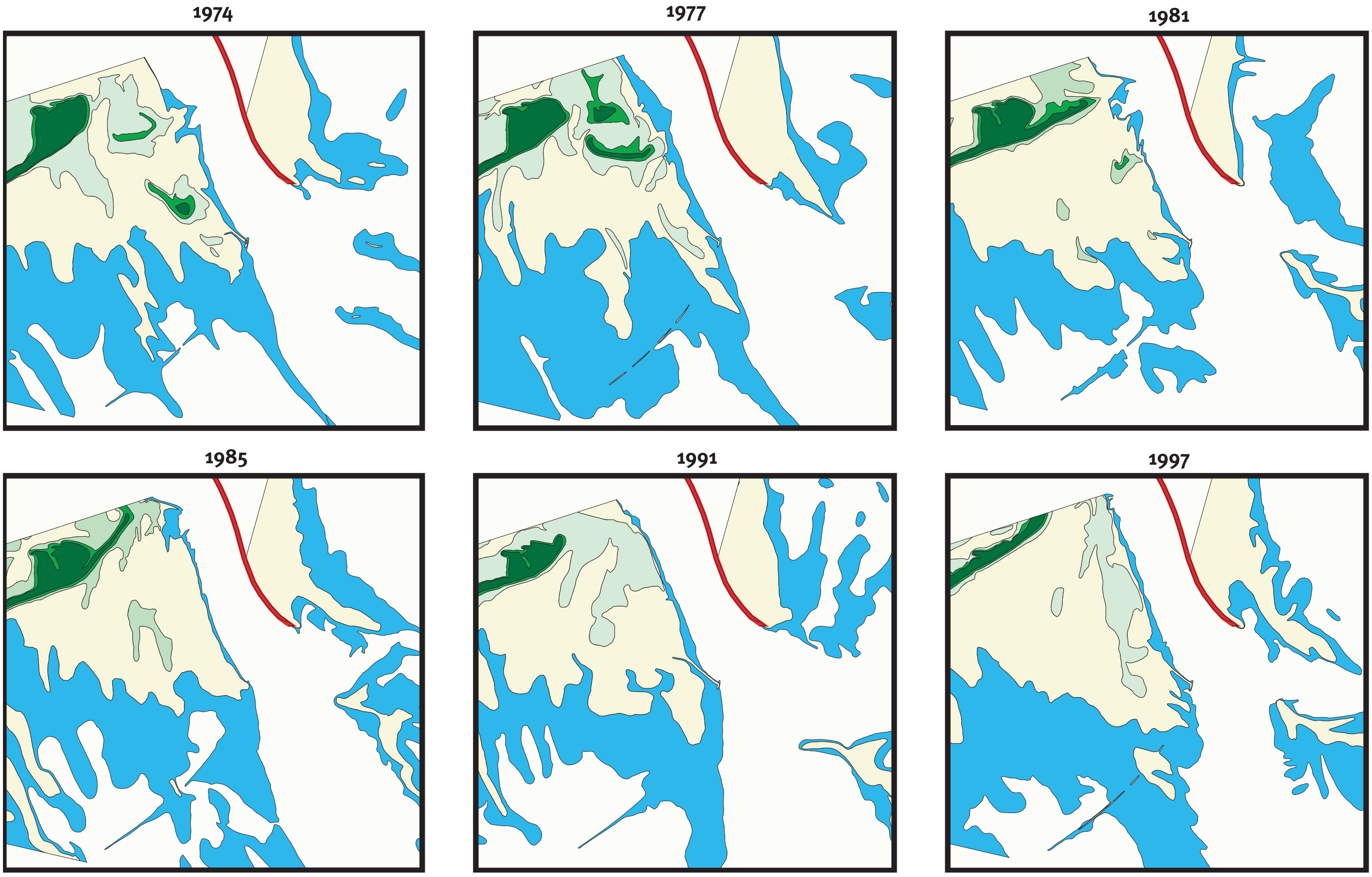


Figure 42 Bar topography, Pioneer River entrance, 1974–97



Before the changes in 1898, the primary sediment deposition zone was further south and inshore of the present location. Over the past 100 years the main deposition zone has been in a delta pattern in the area between the trained river entrance and Flat Top Island. The seaward limit of the delta is gradually extending into the lee of Flat Top Island and is increasing in volume.

Gourlay and Hacker (1986) noted this trend of accretion and predicted that the coastline would eventually form a tombolo in the lee of Flat Top Island. The average annual accumulation of sediments on the entrance bar was determined to be in the order of 40,000m^3, although this was thought to fluctuate in accordance with the episodic nature of flood flows in the Pioneer River.

A sequence of aerial photographs captured in 1962, 1974 and 1993 is seen in figure 41. The 1962 and 1993 photographs show the primary channel with approximately the same length. The 1974 photograph shows a much shorter channel. This can be attributed to the effects of the flood events of 1968 and 1970. The length of the channel is therefore periodically reduced by major flood events, which also have the effect of pushing sediment seaward and extending the width of the delta. The photographs show the main ebb tidal channel extending southward between 1974 and 1993 in response to the growth of the subtidal spit at East Point. The period since 1974 has been characterised by a lack of a major flood in the Pioneer River. Gourlay and Hacker's figures 6.14 and 6.16 show these changes for the period from 1887 to 1979.

The primary mechanism of continuing deposition at the Pioneer River entrance appears to be a widening of the delta in a generally south-easterly direction. Results of a photogrammetric analysis were used, in conjunction with an analysis of hydrographic survey data, to update the earlier estimates of accretion rates (figure 42 summarises the analysis of aerial photography in the vicinity of the river entrance from 1974 to 1997). An average accretion of 55m^3/m/a has been evaluated from survey data, in conjunction with aerial photography and can be assumed to be representative across the river entrance over a distance of 800m.
The net rate of accretion is therefore estimated to be 44,000m^3/a, which

compares closely with Gourlay and Hacker's estimates. It is noted that this estimate is limited by the available data. To improve the accuracy of future estimates, more detailed hydrographic surveys of the entrance area are required.

Gourlay and Hacker (1986) predicted that the low water mark (represented by the –3m AHD contour) at the outer edge of the delta formation would continue to prograde seaward to meet the -3m AHD contour of Flat Top Island by approximately 2042. Based on four surveys of beach profile MAC114 between 1977 and 1992, the average rate of advance has been evaluated as 6.8m/a, supporting the 1986 prediction.

Flat Top Island showing accretion of river sediments.

Town Beach

The section of coast immediately to the south of the Pioneer River entrance (figure 40) has shown a trend of accretion over recent history. Following the major flood event of 1898, the remnants of the spit that previously formed the northern bank of the river broke away from the entrance system and migrated onshore to the northern section of Town Beach. This pattern of onshore migration of sand shoals at the northern end of Town Beach is clearly evident from the photogrammetric analysis of the aerial photography data (figure 43).

South of the Pioneer River, sediment transport processes are characterised by the onshore movement of sand across the tidal flats. The major supply of sediments to Town Beach is from the river entrance bar on the southern side of the main ebb tide channel. Sediments are deposited here by the outgoing tidal and/or freshwater flood flows and driven onshore, primarily by the action of the predominantly south-easterly waves.

The present-day accretion of the northern end of Town Beach is also strongly influenced by the southern training wall structure in the river entrance, which has anchored the beach and isolated it from the river flows. Before the wall was constructed, this section was effectively part of the lower estuary. Sediments were transported into the river mouth by wave action, entrained by the flows in the lower estuary and recycled back out on to the entrance bar. The wall now interrupts this process, resulting in a greater rate of accretion.

In general, the morphology of the Town Beach shoreline changes relatively slowly. The large tide range has a significant control over the inshore sediment transport processes, due to the following phenomena:

- wave energy reaches the upper beach for only a limited amount of time around high water;
- waves are strongly affected by refraction and friction losses over the tidal flats and typically generate only weak longshore currents at the shoreline; and
- inshore tidal flows tend to be cross-shore and are strongly affected by friction losses.

The net rate of longshore sediment transport is difficult to assess as the processes are dominated by cross-shore wave effects and, to a lesser extent, tidal currents. The Unibest CL+ analysis indicates that the longshore transport rate is relatively low and directed northward. At a location near the southern end of Town Beach, a net rate of less than $1000m^3/a$ to the north has been estimated.

For the Town Beach section, data are available for only two survey lines, MAC114 and MAC116. Analysis of beach profile survey data during 1977 to 1997 indicates a gradual accretionary trend (table 21). This is demonstrated by the advance of the MHWS contour (2.3m AHD) at MAC116 by an average of 1.85m/a.

Table 21 also shows the volume change of the upper beach between the 0m and 500m chainages. The apparent erosion of MAC114 is a result of changes of the relict tidal delta of a small creek that has been moving onshore and alongshore since drainage works in East Mackay diverted the flows during the 1960s and is not indicative of the general trend.

The slow accretion observed on the MAC116 upper beach profile (approximately $1m^3/m/a$) is supported by the photogrammetric data (figure 43). At the northern end of Town Beach, the area adjacent to the high water mark has slowly consolidated. There is also evidence of accretion adjacent to the southern training wall.

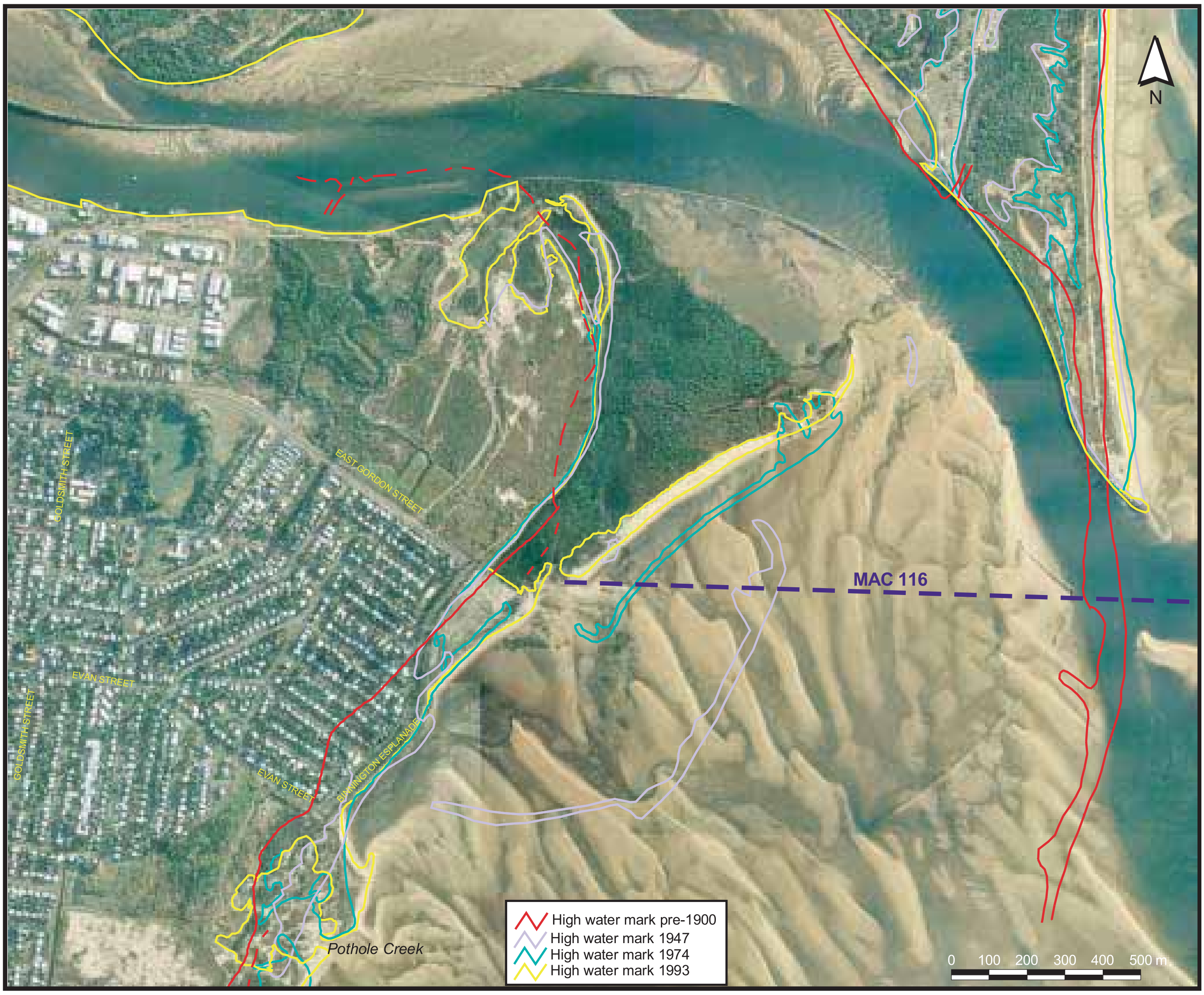
Analysis of the photogrammetric data has also provided an estimate of accretion rates, although it is not conclusive. The total area covered by the 0m AHD contour on the tidal flats immediately south of the river entrance shows a weak trend of accretion although is limited by the spatial extent of the data. The data show large fluctuations over time, which is probably indicative of the accuracy of the analysis. The size of the 0m AHD contour area is increasing at about $2,500m^2/a$, corresponding to a seaward advance of the 0m AHD contour in the order of 2m/a. Assuming a slope of 1:250, this translates into a uniform increase in the bed level of 8mm/a and corresponds to a rate of accumulation in the order of $4000m^3/a$.

Over recent history, the Town Beach coastline has changed considerably as a result of engineering works and natural processes. At the beginning of the 20th century, the East Mackay area was a low-lying wetland area partially inundated by tides and prone to flooding, like the present area adjacent to East Gordon Street. Several major sand extraction campaigns for reclamation works have been undertaken to establish the present-day residential lands.

An unknown volume of material was used in the original East Mackay reclamation works, bounded approximately by Goldsmith, East Gordon, Hoey and Evan Streets. The details of quantities, timing and the location of borrow areas are not available, but it is likely that the majority of the material was sourced from the remnants of the pre-1898 East Point spit, just offshore from the reclamation area.

Binnington Esplanade and the subdivision behind it were reclaimed in 1964, mainly using sand dredged from the tidal flats immediately seaward. Erosion problems soon occurred and a rock wall was subsequently constructed to protect the road.

Figure 43 Town Beach sand shoals (photography captured 17/8/1993)



The dredged area has gradually infilled through onshore and longshore sediment transport, although it can still be seen in recent aerial photographs.

In 1985, the Land Administration Commission (LAC) commissioned the dredging of 280,400m^3 of sand for further reclamation of residential lands. The reclamation was located on the southern side of the small creek at the southern end of Town Beach, locally known as Pothole Creek, effectively extending the original reclamation area. The borrow area, located approximately 500m offshore, has partially infilled although it is still clearly visible in 1997 aerial photography.

As part of the East Mackay reclamation works, the drainage for the area was diverted south into Shellgrit Creek. The small creek at the southern end of Town Beach, locally known as Pothole Creek, subsequently closed, resulting in changes to the inshore sand deposits. The deposits, which were the tidal delta of the creek, have since migrated onshore and alongshore.

Longshore transport has resulted in deposition of the sand on either side of the creek entrance, and towards the aforementioned borrow area near Town Beach.

It is likely that this process will continue, resulting in accretion seaward of the Binnington Esplanade rock wall.

Table 21 Survey data analysis for Town Beach (refer figure 32 for location of profiles)

Survey profile	Volume to 0m contour (m^3/m/a)	MHWS (+2.3m) contour (m/a)	Shoreline (4.6m AHD contour) (m/a)
MAC116	1.12	1.85	2.01 (4m contour)
MAC114	–9.45	–	–0.25

Table 22 Survey data analysis for Far Beach (refer figure 32 for location of profiles)

Survey profile	Volume to 0m contour (m^3/m/a)	MHWS (+2.3m) contour (m/a)	Shoreline (4.6m AHD contour) (m/a)
MAC112	–1.56	–0.02	–0.29
MAC111	–3.40	–0.88	–0.08
MAC110	–3.28	–0.42	–0.66
MAC109	–2.87	–1.24	–1.29
MAC108	1.29	–1.91	–1.85

Far Beach

As at Town Beach, sediment transport in the vicinity of Far Beach is mostly cross-shore with a weak northerly component. At the southern end of Far Beach, the net longshore sediment transport close to the shoreline is approximately zero, although the gross longshore rate is significant. At the northern end of Far Beach, the net longshore sediment transport at the shoreline is directed northward at an estimated rate of less than 1,000m^3/a (an image of Far Beach is given in figure 44).

Before the late 19th century changes to the Pioneer River entrance, this longshore transport rate was approximately balanced by an onshore supply of sediments from the estuary. The historical entrance of the Pioneer River was located just offshore from the centre of Far Beach and provided a continuing source of natural beach replenishment. Therefore over the past 100 years, the onshore supply of sediments to Far Beach has been reduced, resulting in constant shoreline realignment.

Numerical modelling illustrates the indicative flows associated with a medium flood event in the Pioneer River interacting with the nearshore tidal currents and shows the mechanism for deposition of sediments south of the river entrance during flood events. The actual sedimentation patterns during a flood event are influenced by the tidal conditions during the period of peak discharge. Ebb tidal flows tend to turn the river discharge towards the east away from the coast. The input of fluvial sediments to the intertidal area offshore from Far Beach is therefore highly episodic as it depends on the occurrence of a flood event in conjunction with favourable tidal conditions.

Analysis of the beach profile survey data is complicated by the characteristics of the area. The very flat profiles and the slowly changing nature of sand shoals on the tidal flats make it difficult to evaluate trends. In particular, volume calculations are highly sensitive to small survey datum errors over the tidal flats that extend for more than 3km.

Analysis of the available survey data for Far Beach during 1971 to 1997 indicates a trend of erosion (table 22). Southward from Illawong Park, there has been an overall average loss of volume above the 0m AHD contour in the order of 3m^3/m/a and an average recession of the MHWS contour of almost 0.9m/a. The rate of erosion is markedly lower between Illawong Park and Town Beach.

The Far Beach coast has been considerably affected by human activities. There has been a history of sand extraction activities around Far Beach, mostly undocumented, both in the dune areas and on the nearshore tidal flats. Until recently, many areas of dune vegetation were heavily disturbed by pedestrian and vehicle use, resulting in lowered dune levels.

The highest rate of recession of the upper beach has been observed at the southern end of Far Beach near the entrance of Shellgrit Creek. This is partially related to the fluctuations of the primary ebb tide channel of the creek. Modifications to the East Mackay stormwater drainage system over the past 20 years have probably resulted in generally higher flows through the creek entrance and subsequent changes to the local coastal alignment.

Illawong Beach Resort, previously Muddies Crab Farm, has been established near the beach adjacent to the entrance of Shellgrit Creek. The design of the recent upgrade of the resort complex recognised the potential for a serious storm erosion event and a protective rock wall was included as part of the works to provide a line of defence. This wall forms part of the lagoon in front of the resort and to date has not been exposed to storm conditions.

A rock wall has also been constructed seaward of Illawong Park recreation reserve to halt the rate of coastal recession. This has resulted in a localised drop in beach levels and a noticeable recession of the adjacent coastline. These effects are partially related to the effects of the rock wall itself, but are indicative of the continuing erosion trend.

Shellgrit Creek to Bakers Creek

As at Far Beach and Town Beach, the coastal section south of Shellgrit Creek is strongly influenced by the nearshore tidal flats (figure 44). Sediment transport is dominated by wave-driven cross-shore processes across the tidal flats, with a weak southward longshore component at the shoreline. It can be inferred that the null point of net longshore transport is in the vicinity of Shellgrit Creek.

Due to the sheltering effect of Dudgeon Point, the net longshore transport is southward along the inshore zone. The southward sediment transport towards Bakers Creek leads to a general trend of accretion around the creek entrance and a gradual growth of the spit. The zone adjacent to the tidal channel is influenced by wave–current interactions and tends to form a low bank.

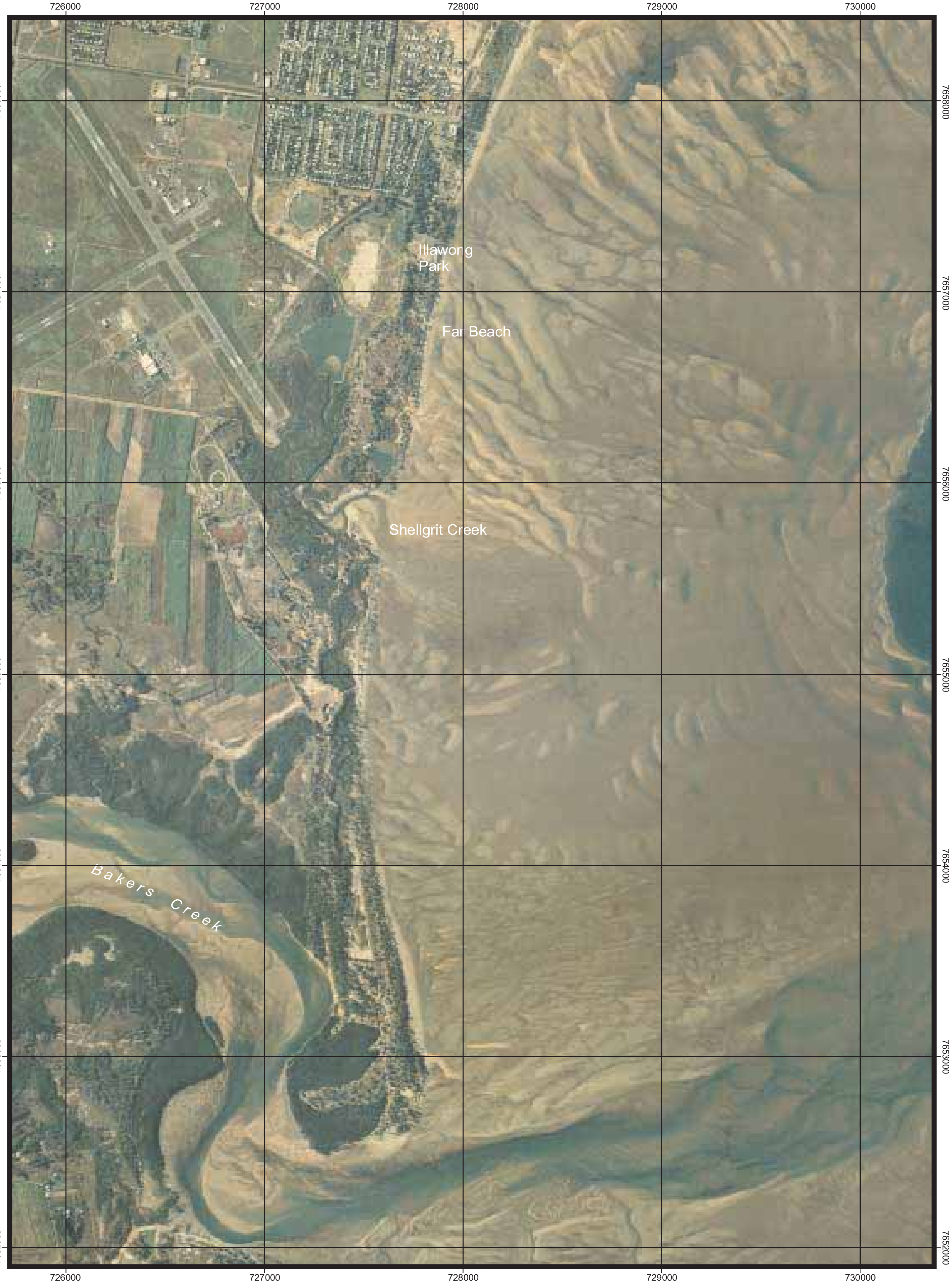
Geological evidence indicates that the spit forming across the creek entrance has grown southward relatively slowly since the Pioneer River established its present course more than 3500 years ago (DPI 1995).

Table 23 Survey data analysis for Shellgrit Creek to Bakers Creek (refer figure 32 for profile locations)

Survey profile	Volume to 0m contour (m^3/m/a)	MHWS (+2.3m) contour (m/a)	Shoreline (4.6m AHD contour) (m/a)
MAC106		insufficient data	
MAC104	–5.03	–0.73	–0.61
MAC102		insufficient data	
MAC100	2.40	2.08	2.02

Rock wall constructed seaward of Illawong Park

Figure 44 Aerial photograph, Bakers Creek to Town Beach



Episodic flood events in Bakers Creek periodically flush the entrance, resulting in irregular erosion/ accretion behaviour of the spit.

Interpretation of aerial photography indicates that sediments entrained in the ebb tide flows are transported seaward towards the edge of the tidal flats. At the seaward edge of the tidal flats, the influence of the predominant south-easterly waves transports the sand back onshore and northward. Further inshore, the transport turns southward towards the creek entrance, completing a circulation.

Geologically, this area appears to be still reaching equilibrium following the change in the course of the Pioneer River more than 3500 years ago. The tidal prism of Bakers Creek was reduced significantly and the creek system has been gradually infilling since. As the catchment is assessed as having low potential to export sediments to the coast (Jones 1987), the source of the accretion is derived from marine sediments. Most of this accretion would have been from the relict delta system soon after the changes to the river; however, it is likely that the infilling is continuing, although at a low rate.

Southern end of the study area showing Bakers Creek in the background and Shellgrit Creek in the foreground.

In Sandringham Bay the estuaries of Sandy and Alligator Creeks behave in a similar manner. Overall, the system is a complex interaction of sediment flows undergoing constant redistribution in response to tidal currents, flood events and storm waves. To the south of Dudgeon Point, the coast is primarily comprised of a series of pocket beaches and it is likely that very little net sediment transport enters Sandringham Bay from the south.

Analysis of the available survey data between 1971 and 1997 is not conclusive (table 23). The results are variable along the coastal section and are affected by analysis difficulties caused by the very flat profiles. In general, the coastline appears to be relatively stable with a small overall accretion trend of the upper beach, particularly at the southern end.

Commercial sand extraction has been permitted in the Bakers Creek estuary and on the tidal flats adjacent to the creek entrance, although the actual rates of extraction have been relatively low compared to the activities in the Pioneer River and along Harbour Beach. Any changes to the adjacent beaches as a result of these extraction works are unable to be detected from the available survey data.

Harbour Beach south

Before the construction of the harbour between 1935 to 1939, Harbour Beach formed a linear beach system from East Point through to Slade Point. The beach is relatively exposed to the prevailing wave climate and is characterised by strong nearshore tidal currents flowing northerly on the ebb and southerly on the flood. The continuous supply of sand from the Pioneer River entrance and the regular onshore winds have combined to generate extensive sand dune formations as shown in figure 38.

Tidal flows have a considerable effect on sediment transport along Harbour Beach. The characteristics of the tides in the region result in a stronger flow in the direction of the ebb. In conjunction with the predominantly south-east wave climate, the net sediment transport is to the north.

At the southern end of Harbour Beach, longshore transport rates are locally very high where the Pioneer River delta attaches to the shoreline. The position of the shoreline fluctuates slightly as shoals merge with the beach; these features gradually wash out in the northerly littoral drift.

The southern breakwater of the Mackay Outer Harbour extends across the full width of the nearshore zone where most of the longshore transport is occurring, and acts as an almost

Table 24 Estimated sand and gravel extraction rates ($10^3 m^3$)

Source:	Gourlay and Hacker Pioneer River		Mackay Harbour Board Estimates			Total
Site:	Upstream of Hospital	Cullen Island	Pioneer River	Harbour Beach	Outer Harbour to Lamberts Beach	Pioneer River
Year	1969				25*	150.0
1970				25*		30.4
1971				25*		30.4
1972				25*		30.4
1973				25*	120.0	30.4
1974			972*	25*		30.4
1975				25*		30.4
1976	79.9			25*		79.9
1977	119.8			25*		119.8
1978	88.3	322.0		25*		410.3
1979	59.9	150.0		25*		209.9
1980	203.1	150.0	203.0	75.0		353.1
1981	105.4		113.0	54.0		113.0
1982	90.0		90.0	108.0		90.0
1983			122.0	60.0		122.0
1984			167.0	28.0		167.0
1985			70.0	18.0		70.0
1986			69.0	27.0		69.0
1987			52.0	16.0	340.0	52.0
1988			76.0	21.0		76.0
1989			98.4	17.5		98.4
1990			92.4	26.1		92.4
1991			73.4	42.9		73.4
1992			58.0	46.6		58.0
Total:	**746.4**	**622.0**	**2256.2**	**815.1**	**610.0**	**2436.7**
Average:				**34.4**	**20.0**	**105.9**

N.B. * indicates approximate value only.

Table 25 Survey data analysis for Harbour Beach south (refer figure 32 for location of profiles)

Survey profile	Volume to 0m contour ($m^3/m/a$)	MHWS (+2.3m) contour (m/a)	Shoreline (4.6m AHD contour) (m/a)
MAC120	2.06	0.71	0.50
MAC122	0.31	0.10	–0.15
MAC124	–1.08	0.42	0.41

complete barrier to the northward transport of sand. Aerial photography shows that the shoreline has accreted immediately updrift of the southern breakwater since the harbour was constructed. The pre-construction coastal alignment has been affected for approximately 800m south of the walls.

Following the recent construction of the small boat harbour extending south of the original harbour walls, this process is expected to be repeated. In the absence of artificial sand removal, the coastline would accrete significantly.

There is potential for a small rate of sediment transport to naturally bypass the harbour walls. Numerical modelling has indicated that the predicted rates of natural bypassing are very low in comparison with the transport rates along the beach; however, if the accretion process were left to continue, this rate would increase. This could result in a significant reduction in depth in the harbour entrance.

In the inshore region adjacent to the harbour, the tidal flow characteristics and wave conditions are affected considerably by the breakwaters. Tidal flows downstream of the

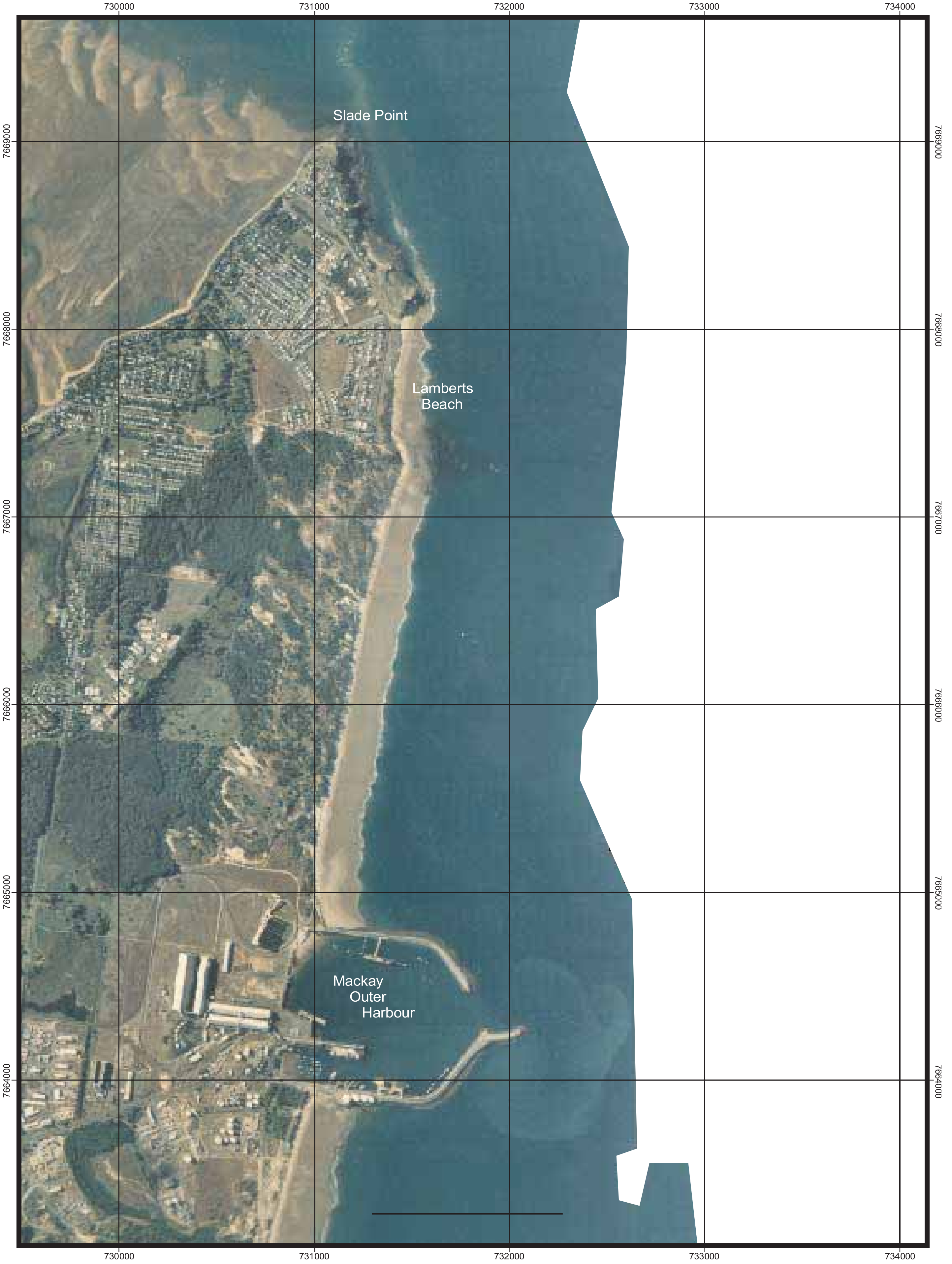
Coastal accretion has occurred south of the harbour walls.

harbour wall are reduced for several hundreds of metres. Upstream flows are accelerated slightly and diverted offshore close to the harbour walls. The residual tidal flows – the net movement of water over a full tidal cycle – are therefore directed towards the harbour and with a small offshore component.

Significant quantities of sand have been extracted from the southern section of Harbour Beach since the harbour was first established in 1935. The current permitted rate of extraction is up to 70,000m^3/a for two sites between East Point and the harbour (GHD 1998). Table 24 provides estimates of sand extraction over the period 1980 to 1992; during this time the average rate of extraction has been 45,000m^3/a.

A condition of the extraction permits requires that surveys of the beach and inshore areas in the permit area are undertaken so that the removal of sand does not cause localised erosion. The analysis of survey data and COPE profile data indicates that this section of coast has remained relatively stable over the past 25 years (table 25).

Figure 45 Aerial photograph, Harbour Beach north to Slade Point



Harbour Beach north

North of the harbour to Slade Point, the beaches are similar in character to Harbour Beach south, although the dune systems are markedly higher towards the northern end. Apart from the levelling of dunes associated with the harbour construction and some isolated commercial sand extraction activity, the area remains intact. Slade Point Reserve and the Mackay Port Authority Conservation Reserve have been established to protect the conservation values of the high dune fields and freshwater wetlands in this area (figure 45 shows the 1997 aerial photograph).

The harbour walls are of sufficient scale to significantly shelter the beaches immediately adjacent from wave conditions. This effect, in conjunction with the altered tidal current residuals, results in the tendency for accumulation of sediments immediately to the north of the harbour walls. The accretion of sediments has been assisted by the placement of significant quantities of dredged sand on the beach north of the harbour as part of the Mackay Port Authority's capital dredging works program. More than 610,000m^3 of mainly sandy material was placed between 1968 and 1988. The majority of this material has been transported northward in the littoral flow, but some has remained in the deposition zone in the lee of the harbour walls. Survey data and aerial photographs show a small trend of beach accretion for up to approximately 1km north of the breakwater. Information supplied by the Mackay Port Authority indicates that undocumented volumes of sand extracted from Harbour Beach south were periodically deposited downdrift of the northernmost harbour wall.

The survey data show an erosion trend of about 19m^3/m/a approximately in the centre of the northern section of Harbour Beach (table 26). The upper beach, represented by the 4.6m AHD contour, shows a consistent recession of 0.85m/a. From these results, it is apparent that the blocking effect of the harbour and the extraction of sand are resulting in continuing downdrift erosion. A time series of the horizontal distance between the COPE pole and the 4.6m AHD contour under the COPE upper beach profile surveys clearly shows the continuing erosion trend (figure 46).

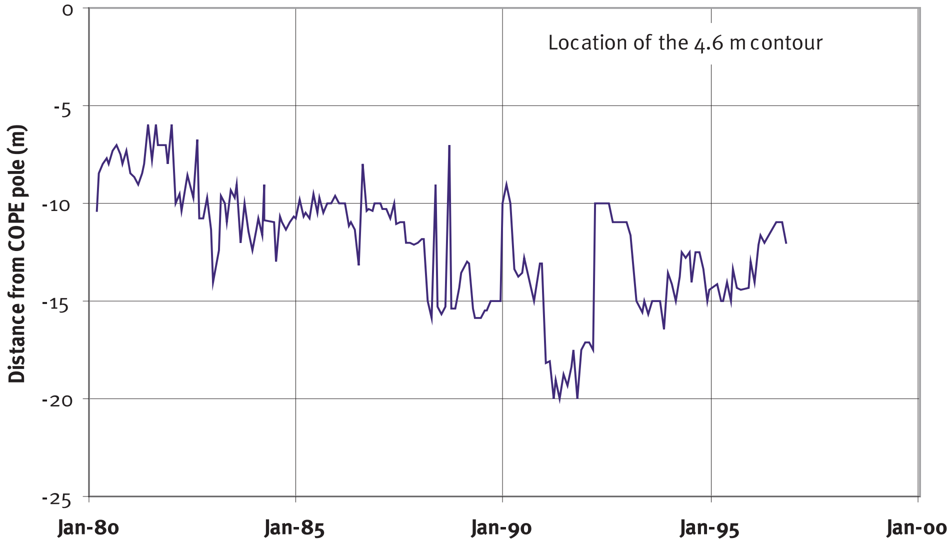
Analysis of the available survey data over the period 1971 to 1997 is summarised in table 26. The results support the above description of the recent changes to this coastal section. Taken as a whole, the northern 1km of Harbour Beach is estimated to be eroding at an average rate of more than 7000m^3/a.

A previous management practice was to strip vegetation from sections of the dune system of Harbour Beach north to encourage sand to blow inland. At the time it was anticipated that development would eventually extend into the wetland area behind the dunes, which would require a large volume of fill. It was considered that it was significantly less expensive to let nature fill the area with wind-blown sand.

The rate of net longshore sediment transport at the centre of Harbour Beach north has been calculated as 33,000m^3/a. This is close to the computed rate south of the harbour and is consistent with the equilibrium alignment of the beach before the construction of the harbour.

A coastline model of Harbour Beach has been established using Unibest CL+, which simulates the movement of the average position of the shoreline in response to changes in the longshore sediment transport. In the section north of the harbour, the model simulates the downdrift erosion caused by the blocking effects of the harbour walls, and includes the sand placement. The simulation was run for a 50-year period assuming no sand placement occurs north of the harbour. For this case, the model indicates a recession in the order of 80m at the centre of Harbour Beach north.

Figure 46 Time series of upper beach movements, Harbour Beach north



High dunes at the northern end of Harbour Beach

Table 26 Survey data analysis for Harbour Beach north (refer figure 32 for profile locations)

Survey profile	Volume to 0m contour (m^3/m/a)	MHWS (+2.3m) contour (m/a)	Shoreline (4.6m AHD contour) (m/a)
MAC130	26.84	0.18	0.17
MAC132	18.50	0.46	–0.04
MAC134	–18.61	–0.21	–0.85

Lamberts Beach

Lamberts Beach is separated from Harbour Beach by a small bedrock outcrop that intrudes slightly into the longshore sediment transport flow (figure 45). Aerial photography shows a shallow inshore shoal often forms at the southern end of the beach as a continuation of the main sediment transport pathway.

The upper beach in this section takes the form of a pocket beach alignment between the two rocky outcrops at either end, although its configuration is sustained by the throughput of longshore sediment transport. The stronger tidal flows and the greater exposure to waves combine to generate a slightly higher energy regime than that at Harbour Beach. As a consequence, Lamberts Beach tends to be steeper and has a generally coarser median grain-size.

Volume changes on Lamberts Beach are represented by only one survey profile. MAC137 commences in the centre of Lamberts Beach. The adjacent profiles MAC136 and MAC138 have been established on the rocky headlands at each end of the beach and therefore do not provide information on upper beach changes.

Analysis of the MAC137 survey data, consisting of six dates, indicates a trend of erosion over the period 1971 to 1997. Above the –10m AHD contour, the centre of the beach has an average loss of more than $10m^3/m/a$. Applying this rate to the effective length of the beach, the average loss has been $6{,}200m^3/a$.

Similarly, the upper beach of MAC137 has receded by an average of 0.8m/a. This erosion trend is indicative of the overall downdrift erosion observed on Harbour Beach north.

Slade Point Beach

Slade Point Beach faces approximately north-east and has a potential longshore sediment transport rate much higher than the actual supply. As a result, this section has a small-volume sandy upper beach perched on a mainly rocky substrate backed by rocky cliffs. The upper beach is episodically supplied by cross-shore sediment transport processes and is dependent on the favourable combination of high water levels and accretionary wave conditions.

Examination of historical aerial photography shows that a quantity of aeolian sand once existed behind the Slade Point headland (figure 45 shows this in 1997 and figure 47 shows this in 1962) .

It is likely that this source of overland sediment transport constituted a proportion of the supply of sand to Slade Point Beach in the past. Residential development of Slade Point has necessitated stabilisation of the dunes, thereby reducing the overall supply of sand to the area.

Bypassing of Slade Point

The continuation of the net northward sediment transport along Lamberts Beach and Slade Point, driven by longshore wave-induced currents and tidal flows, bypasses the headland and disperses in a complex pattern. At the headland, sediment transport separates into two distinct pathways:

- west across the intertidal flats of Slade Bay; and
- north-west to a nearshore sand shoal system east of Blacks Beach.

The sediment transport across Slade Bay is further separated by the channel of McCreadys Creek (figure 38 shows these processes schematically and figure 48 shows the 1997 aerial photography from this area).

The bypassing of Slade Point tends to be episodic in response to the variability of the wave climate and results in a series of sand shoals forming in the lee of the headland. This process is strongly associated with storm wave events. Storms with a predominantly easterly component produce relatively low longshore transport from Lamberts Beach but a high transport across Slade Bay, thus producing a net deficit of sand in the lee of the headland. Events with a mainly southerly component tend to produce the opposite. High transport rates along Lamberts Beach move large quantities of sediment around the headland, which then accumulate in the relatively sheltered zone as a series of distinct banks.

The migration of shoals across the intertidal platform is further interrupted by lateral tidal flows in and out of the bay and the creek system. The shallow braided channel tends to accentuate the formation of the shoals along the outer edge of the tidal flats.

The momentum of the strong ebb tidal currents flowing along the eastern shoreline of the headland, in conjunction with waves breaking on the rocky shoreline, drive a proportion of the bypassing sediments onto a system of shoals north of Slade Point. These sandy shoals have formed broadly on a north–south axis and extend across Slade Bay almost to Dolphin Heads, (figure 47). The northern shoals, closest to the coast opposite Dolphin Heads, are considerably shallower and are visible during periods of low water (figure 48).

Grain size analysis of sediments in these nearshore shoals indicates that the median diameter of material on the deeper, southern section is coarser than that of sediments in adjacent areas. This feature is probably a natural sorting process caused by differential settlement of the coarser fractions.

Figure 47 Slade Point, 1962

Figure 48 Aerial photograph, Slade Point to Dolphin Heads

The position and shape of the nearshore shoals appear to be controlled by tidal flows as shown in figure 20, although on occasions storm wave conditions move this material onshore towards Dolphin Heads to rejoin the littoral system. Analysis of hydrographic survey data shows that the landward edge of the northern shoal has been slowly migrating onshore since the first available survey data in 1977. The survey data also show that the nearshore shoal has increased in volume at the northern extremity over the past 20 years.

It is likely that the volume of the northern section of the shoals is fluctuating over a relatively long time scale, as the shallower section builds in height and then episodically breaks away to migrate onshore. This therefore has implications for the downdrift beaches which episodically receive additional quantities of sand. The limited data on the historical changes in this area do not allow an accurate estimate of this process to be made.

Slade Point western shore

The majority of the sediment transport across Slade Bay is along the outer margin of the tidal flats, influenced by the predominantly south-easterly wave climate. Some of these bypassing sediments are transported onshore and across the tidal flats by wave energy approaching from the north-easterly sector and waves refracted around the headland.

A proportion of this onshore transport is along the western shore of Slade Point towards the entrance of McCreadys Creek. Due to the sheltering from wave energy and the relatively weak tidal currents, the morphology of this area tends to change relatively slowly under ambient conditions. The inshore zone generally comprises a rocky substratum overlain by a thin veneer of sand and patches of mud.

Historical aerial photography shows a series of distinctive sand shoals moving across the inshore zone towards the entrance of McCreadys Creek. Through examination of this sequence, estimates have been made of rates of travel of these shoals. An indicative time scale of 25 years has been estimated for travel of a shoal along the western shore of Slade Point.

The inshore zone has shown significant variability in response to the episodic sediment supply. A stand of mangroves has grown approximately halfway along the shoreline. The presence of the mangroves indicates that this section is relatively sheltered from incident wave energy and ebb tidal flows from McCreadys Creek. Occasionally the mangroves are smothered by the passage of a sand shoal, resulting in a short-term dieback.

The variability in sediment supply along the western shore of Slade Point is related to the episodic bypassing of Slade Point and the fluctuations of the ebb tidal channel. As a result, the system is vulnerable to high-energy wave events such as cyclone swell refracting around the headland, and north-easterly storms, which generate bursts of high-rate, short-term longshore transport. Due to the variable distribution of sediment near the shoreline, differential longshore transport during storms results in erosion in some sections and accretion in others. This effect is more apparent further into the embayment, where the primary channel of McCreadys Creek is close to the shoreline.

The sediment transport along the western shore of Slade Point appears to be approximately balanced by the outflow driven by the ebb tidal currents from McCreadys Creek. Sediments are transported seawards in the high velocity flow to rejoin the littoral transport along the margin of the tidal flats.

Analysis of hydrographic survey data is complicated by the variability caused (table 27) by the movement of the shoals. Overall trends in the data indicate that the volume of the tidal flats in this area is relatively stable. The shoreline position, determined from aerial photography, has also been relatively stable. In geological terms, it appears that the embayment has reached an approximate equilibrium and there is no clear evidence indicating a recent erosion trend.

Property owners have constructed a series of rock walls along the western shore of Slade Point to protect residential allotments from episodic erosion. Close to the entrance to McCreadys Creek, the walls also have the effect of training the primary tidal channel.

Table 27 Survey data analysis for Slade Bay (refer figure 32 for profile locations)

Survey profile	Volume to 0m contour ($m^3/m/a$)	MHWS (+2.3m) contour (m/a)	Shoreline (4.6m AHD contour) (m/a)
MAC146	insufficient data		
MAC147	15.99	insufficient data	
MAC148	26.20	insufficient data	
MAC149	8.80	insufficient data	

Blacks Beach

The alignment of Blacks Beach and the configuration of the tidal flats are controlled by the bedrock outcrops of Slade Point and Dolphin Heads. Relatively recent deposition of sediments, sourced mainly from the Pioneer River, has formed the barrier system on the present-day alignment following the Holocene transgression. This has also resulted in the formation of a low-lying area behind the barrier comprising the catchment of McCreadys Creek.

Blacks Beach is more northerly facing beach than any of the other open coast beaches in the Mackay area. This is in response to the sheltering effect of the Slade Point headland relative to the predominant south-easterly wave climate and the complex pattern of sediment transport across Slade Bay. At the northern end of Blacks Beach, the beach narrows and is close to the rock cliff behind. The high northerly potential longshore transport rate in this section is greater than the available supply, preventing the establishment of an upper beach.

Along the southern end of Blacks Beach, the net longshore transport is directed weakly southward towards the entrance of McCreadys Creek. The ebb tidal flow of McCreadys Creek tends to transport this material back offshore to rejoin the wave-driven sediment flows along the margin of the tidal flats.

The southern end of the beach terminates as a spit forming across the entrance of McCreadys Creek. The McCreadys Creek estuary system has accumulated a large quantity of sand and silts, resulting in extensive areas of supratidal flats and intertidal wetlands.

The main sediment transport pathway across Slade Bay is along the outer margin of the tidal flats; approximately halfway along Blacks Beach, a distinct convex bulge in the coastal alignment can be seen where this sediment transport pathway reattaches to the shoreline (see figure 48).

The net longshore sediment transport rate at the northern section of Blacks Beach has been estimated as 28,000m^3/a (table 20). As the survey data between Slade Point and Dolphin Heads do not show a clear trend of accretion, it may be inferred that the difference between this rate and the longshore sediment transport rate at Lamberts Beach is equal to the rate of transport to the nearshore shoals. This rate is therefore approximately 5000m^3/a. It is likely that these sediments accumulate on the nearshore shoals and periodically re-enter the littoral system at Dolphin Heads as a series of sand slugs.

An examination of survey data and aerial photographs indicates that the location of the sediment transport reattachment point near the centre of Blacks Beach, and hence the coastline bulge, varies considerably. This variation is related to variability in the net longshore transport rate, primarily in response to individual storm events or sequences of storm events. During storm events, high wave energy penetrates into the embayment, generating high sediment transport rates that reduce the overall volume of material, subsequently tending to move the shoreline bulge southward.

The coastal alignment in the middle of Blacks Beach therefore has a large potential for variability (figure 49 shows the variation of historical shorelines, derived from aerial photography). Rock walls have been constructed on some sections of the upper beach to protect freehold properties from erosion; these have artificially constrained the coastline.

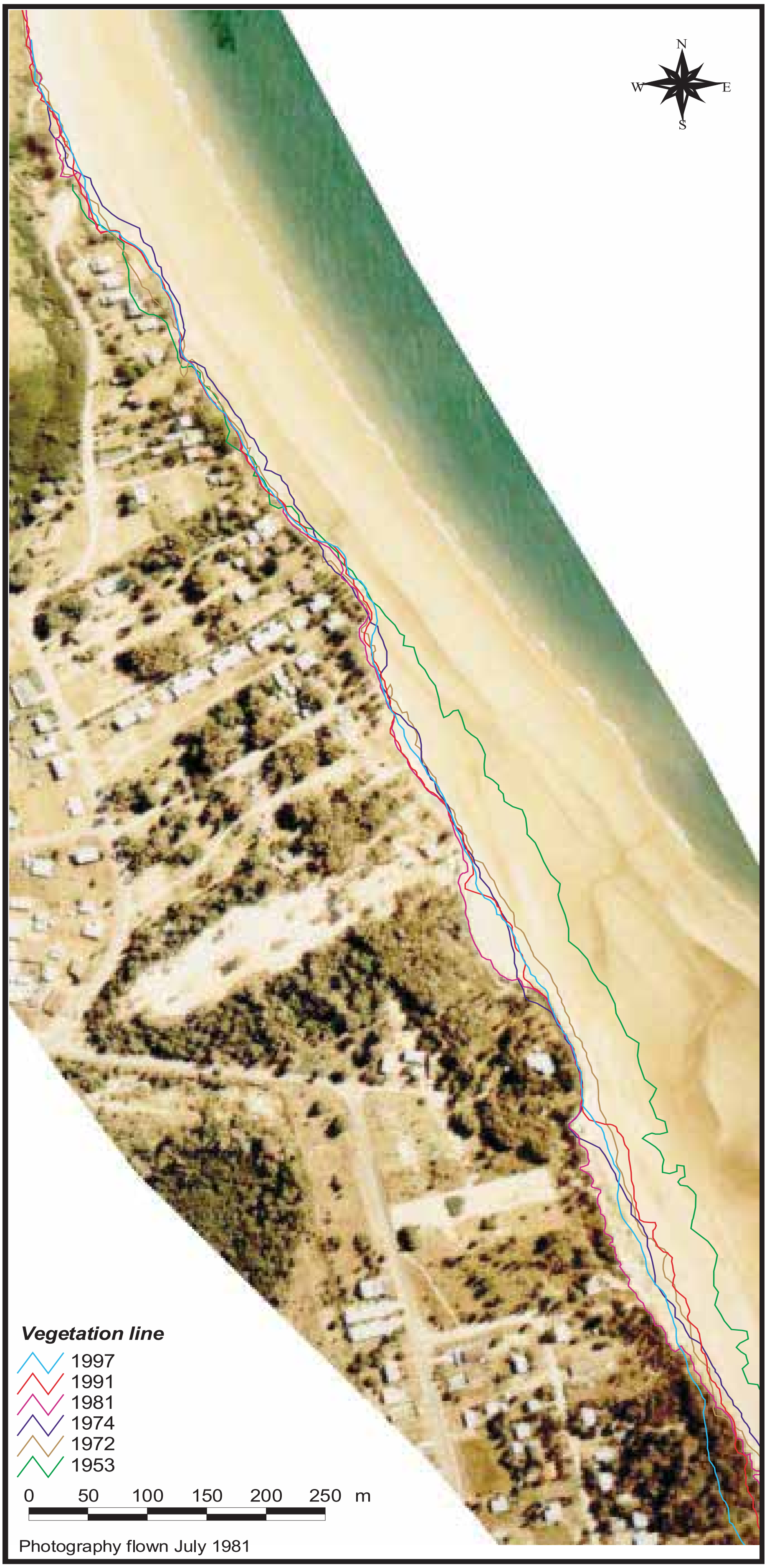
It is apparent that the coastal alignment of the central section of Blacks Beach was relatively advanced when property boundaries were first surveyed. In the absence of the rock walls, the natural position of the coastline would tend to fluctuate landward of these boundaries. Since the establishment of the first residential properties along Blacks Beach before the 1950s, the area has suffered erosion. This may be explained by two factors:

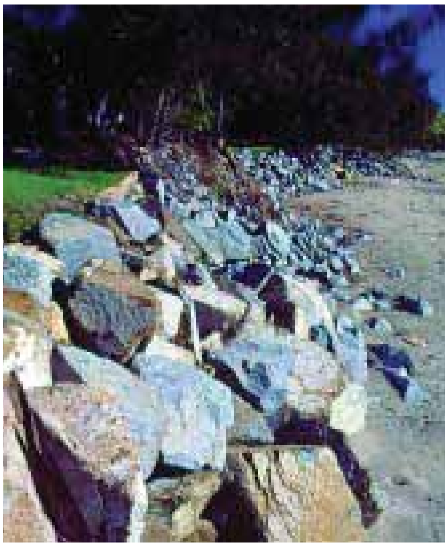
- the long-term, natural fluctuations of the coastline in response to the variability of sediment transport across Slade Bay; and
- the presence of the rock walls on the upper beach, which have the effect of discouraging the natural rebuilding of the beach and dune system.

Analysis of survey data over the period 1977 to 1997 show significant variations due to fluctuations in the seabed levels across the intertidal flats, particularly the outer section (table 28). These correspond to the passage of shoals through the area. Key points may be summarised as follows:

- the profiles of the beach sections around the centre of Blacks Beach are highly variable. The profile at MAC157 (figure 32 shows the location), which is close to the sediment transport reattachment point, shows significant phases of accretion and erosion around the high water mark although the location of the toe of the dune is relatively stable;
- to the south, survey data at MAC156 show a clear trend of recession. The toe of the dune at this point has been receding at an annual average of more than 1m since 1977;

Figure 49 Historical shorelines, Blacks Beach



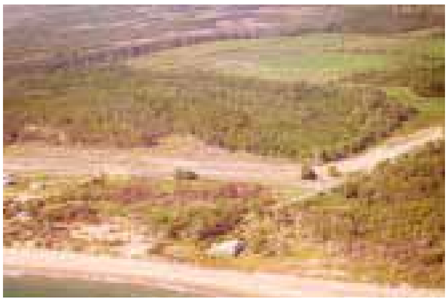


A series of rock walls have been constructed at Blacks Beach.

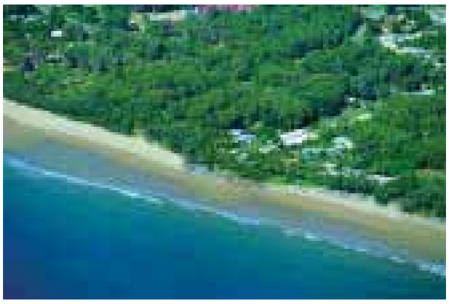
- at MAC158 and MAC159, adjacent to the long section of rock wall, the upper beach showed a recession of more than 20m between the 1978 and 1979 surveys and has been accreting gradually since. This erosion can be attributed to tropical cyclone Kerry in March 1979;
- the profiles at the southern end of Blacks Beach, lines MAC152 to MAC155, are considerably affected by seabed fluctuations caused by the passage of shoals through the area. Analysis of these data are inconclusive although it can be inferred that the shoreline has been relatively stable over the past 20 years; and
- at the northern end of Blacks Beach, lines MAC160 and MAC161 show a trend of erosion over the nearshore profile to the −5m AHD contour. The upper beach in this section is at the base of the rocky cliff.

Table 28 Survey data analysis for Blacks Beach (refer figure 32 for location of profiles)

Survey profile	Volume to 0m contour (m^3/m/a)	MHWS (+2.3m) contour (m/a)	Shoreline (4.6m AHD contour) (m/a)
MAC152	−0.95	−0.24	−0.27
MAC154	48.62	0.10	−0.42
MAC155	0.22	0.77	0.30
MAC156	−22.51	−1.18	−1.80
MAC157	8.45	−0.07	0.97
MAC158	7.60	0.31	−0.53
MAC159	−2.32	−0.15	−0.48
MAC160	−2.36	−0.20	−0.49
MAC161	−6.05	−0.03	0.08



Blacks Beach 1962



Blacks Beach 1997

Dolphin Heads and Eimeo

The net northward sediment transport along Blacks Beach passes through to Bucasia Beach and Shoal Point via Dolphin Heads and Eimeo Beach. In addition, the nearshore sand shoals off Blacks Beach have a slow onshore feed back into the littoral system. The reattachment point appears to be in the vicinity of Dolphin Heads (figure 50).

The beaches to the west of Dolphin Heads are relatively exposed to wave energy from the east and north-east. The rate of longshore sediment transport is generally higher than the available supply of sand, preventing the formation of a sandy upper beach. The rocky substrate is often exposed and the intertidal area is strewn with small boulders and cobbles. Further west along the Dolphin Heads shoreline is a low dune system, which is formed mainly by wave action. Excavations in this area have revealed the presence of large cobbles below the surface that have probably been transported from the headland by the action of storm waves. This indicates the potential for the penetration of high wave energy through this section.

A number of short rock groynes have been constructed on the rocky intertidal platform in an attempt to encourage the sedimentation of sandy material near the shoreline. In addition, low rock walls have been constructed to halt erosion along the seaward boundaries of freehold properties.

Eimeo Beach has formed into a barrier system between Dolphin Heads and Eimeo headland as part of the net northward longshore sediment transport regime. A small tidal waterway drains the low-lying area behind the beach into the southern end of the embayment.

Eimeo Beach features a relatively wide area of tidal flats at the southern end, narrowing at the northern end. This area comprises a thin layer of sand overlying a rocky platform; patches of bedrock outcropping can often be seen. The main sediment transport pathway along Eimeo Beach is through the intertidal area where an inshore bank forms in the lee of the Dolphin Heads and interacts with the tidal flows from the creek. The intertidal banks can vary considerably in shape in response to an irregular supply of sand bypassing the headland.

The presence of the bedrock platform extending from Dolphin Heads and the volume of sand in the intertidal banks influence the alignment of Eimeo Beach, particularly at the southern end. The volume of this section is dependent on the configuration of the inshore sandbanks

Figure 50 Aerial photograph, Dolphin Heads to Shoal Point

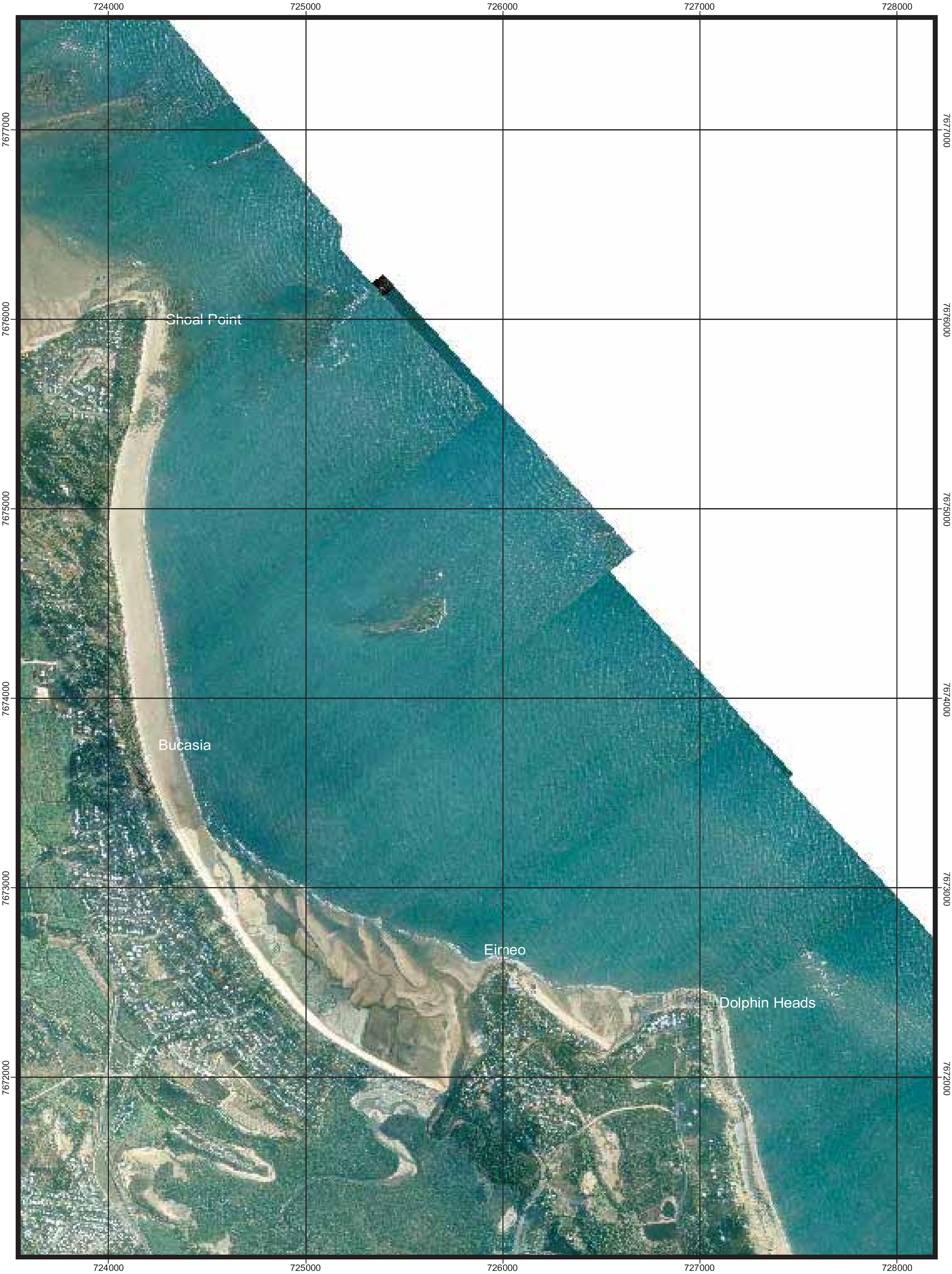


Figure 51 Historical shorelines, Dolphin Heads and Eimeo (photography captured 17/8/1993)

and can be prone to erosion in high wave energy and water level storm events.

Rock walls have been constructed on the seaward boundary of several properties at the end of the spit as protection from damage from storm waves.

Eimeo Beach volumetric changes have been derived from five hydrographic surveys of survey line MAC167 between 1978 and 1997.

This profile extends offshore from near the southern end of the beach. The survey analysis indicates a continuing trend of erosion, although it is probably related to cyclic fluctuation with a time scale longer than the 20 years of survey data. The average loss of volume above the –5m AHD contour has been 7.5m^3/m/a; however, there appears to be little continuing change in the position of the upper beach.

A proportion of the sediment bypassing Eimeo headland is transported along the western shore of the headland towards the entrance of Eimeo Creek. In a similar process to that seen on the western shore of Slade Point, this transport is episodic in nature and the shoreline often shows significant fluctuations as slugs of sand move through. Freehold properties front the majority of this western shoreline and a number of low rock walls have been established for protection against sequences of erosion. Some parts of this coastline are relatively low-lying and prone to flooding.

An analysis of historical shorelines shows the potential for large changes in coastline position through this western shoreline, as illustrated by figure 51.

Bucasia Beach

The extensive barrier system of Bucasia Beach shows a morphology similar to that of Blacks Beach, although the embayment is not as deeply indented as Slade Bay (figure 50). The wide tidal flats in the lee of Eimeo headland narrow to form a gently curving sandy beach at the northern end towards Shoal Point. At the southern end, Eimeo Creek drains the tidal wetlands behind the coastline.

Sand bypassing Dolphin Heads and Eimeo disperses across the embayment in a complex pattern. The bypassing sediment flow generated by the action of waves and tidal currents interacts with the outflow of Eimeo Creek to form a sequence of intertidal banks. These banks are driven across the bay and onshore by wave action. In comparison with Slade Bay, there is relatively more wave penetration into the intertidal area, which results in a wider sediment transport pathway. The pronounced shoreline bulge seen on Blacks Beach at the point of attachment is less evident on Bucasia Beach, although historical shoreline data show potential for some changes at the southern section.

At the southern extremity of Bucasia Beach, a spit has formed across the entrance to Eimeo Creek. The growth of the spit appears to be regulated by southward longshore transport fed from shoals moving onshore from the intertidal flats. The location and configuration of the creek entrance and the primary ebb tide channel have remained fairly stable over the past 25 years, although this area could be subject to overtopping during severe storm conditions.

Table 29 Survey data analysis for Bucasia Beach (refer figure 32 for location of profiles)

Survey profile	Volume to 0m contour ($m^3/m/a$)	MHWS (+2.3m) contour (m/a)	Shoreline (4.6m AHD contour) (m/a)
MAC172	8.98	0.52	0.28
MAC173	2.08	0.60	0.29
MAC174	7.57	0.78	0.38
MAC175	17.59	0.77	0.76
MAC176		insufficient data	
MAC177		insufficient data	
MAC178	14.62	0.78	0.36
MAC179	11.82	0.05	–0.13
MAC180	9.22	0.03	–0.43

Bucasia Beach has formed as a wide sandy beach with a well-developed dune system. The nearshore area is relatively shallow and features two small rocky islets offshore from the northern end of the beach. The coastal alignment of this section of the beach is influenced by the sheltering effect of the southernmost islet, and it forms a slight convex shape approximately 1.6km south of Shoal Point.

Geological evidence indicates extensive transport of sand past Shoal Point into Sand Bay and northward into the Blackwood Shoals area (Jones 1987). Analysis of survey data from 1977 to 1997 is summarised in table 29. The data show a consistent trend of accretion throughout the Bucasia Beach section.

The net longshore sediment transport rate at the northern section of Bucasia Beach has been estimated to be 20,000m^3/a (table 20). The analysis has shown that the rate of sediment transport into the embayment is higher than the rate at which sediment is transported northward past Shoal Point. This result is consistent with the observed accretion trend throughout Bucasia Beach. It is apparent that the embayment is yet to reach equilibrium in response to the changed conditions that occurred some 3500 years ago, when the Pioneer River changed course to its present alignment.

16 Coastal management

Introduction

Coastal resources in the Mackay region are highly sought after for competing uses including residential, commercial, tourism and recreation. Effective management is necessary to ensure that the natural values and attributes of the coast are preserved while economic development and expected rates of population growth are accommodated.

In the past, development within the coastal zone has often been undertaken with limited understanding of natural processes, and in many cases this has led to inappropriate use of coastal lands. Uncontrolled urban development, recreation and tourism activities can lead to the degradation of the natural values of the coast. Encroaching infrastructure and development result in increased land values; however, they can also result in a demand for engineered coastal protection works such as rock walls. The primary coastal management issue considered in this study is the interaction of various land uses in the region with hazards related to coastal processes, such as erosion and storm tide flooding.

It is important to manage existing and future developments to ensure that they do not cause any significant or unacceptable increase in hazard or risk of damage by adverse interaction with coastal processes. This approach supports the general principle of the sustainable use of coastal resources and is an essential component of sound coastal management. Additional considerations include:

- the sustainable use of sand and gravel resources;
- the conservation of critical habitats and areas of important remnant vegetation; and
- protection of sensitive coastal wetland areas.

Coastal hazards

Coastal hazards are the result of developments poorly located with respect to prevailing coastal processes. A number of hazards have been identified in the Mackay coastal region, including:

- short-term beach erosion associated with storm events;
- coastline recession;
- recession related to climate change and sea-level rise; and
- storm tide flooding.

As a general principle, it is desirable to avoid the exposure of communities to coastal hazards in order to minimise economic and social costs. Often the most cost-effective management of coastal hazards is achieved through the establishment of buffer zones along the shoreline.

The *Coastal Protection and Management Act 1995* also provides for buffer zones in the form of erosion prone areas, which are beachfront lands intended to remain free of development. Erosion prone areas established under the Act are primarily intended to allow for fluctuations in coastline position caused by natural erosion processes. These buffer zones are also important for the preservation of natural coastal processes and the establishment of a natural barrier against storm tide inundation. Erosion prone area widths for the Mackay region have been available for many years and are the basis for much of the Environmental Protection Agency's coastal management activities. Information developed as part of this study has been used to review and revise erosion prone area widths in the region.

Erosion prone area widths

The formula adopted by the Environmental Protection Agency to determine widths of erosion prone areas for a particular section of beach is:

$$E = [(N \times R) + C + G] \times (1 + F) + D$$

where:

E is the erosion prone area width (m)
N is the planning period, taken as 50 years
R is the rate of long-term recession (m/a)
C is the short-term erosion (m)
G is the erosion due to sea-level rise associated with the greenhouse effect
F is a factor of safety, taken as 40 percent
D is the dune scarp component (m)

The components of erosion prone area width calculations are shown graphically in figures 52 to 54. It is noted that the values of N and F are relatively subjective quantities. The values of 50 years and 40 percent, respectively, have been selected to conform with previous calculations of erosion prone area widths.

The calculation of D, the dune scarp component, is required to allow for slumping of the erosion scarp above the wave run-up level. This is generally required because numerical methods for calculating the short-term erosion profile typically do not provide information above the water level.

A review of existing erosion prone area widths has been undertaken for the Mackay region. This review has been undertaken for open coast sections only. Erosion prone areas within estuaries are defined as a line 40m landward of the mean high water mark at spring tides or the plan position of the highest astronomical tide, whichever provide the greatest erosion prone area width.

Estimates for short and long term erosion have been made in areas where rock walls currently exist. Walls constructed seaward of private properties principally for the purposes of property protection are generally not considered as public assets even though they may be partially on public land. In terms of long term coastal recession, it cannot be assumed that existing walls will be maintained to the standard required for coastal protection. For this reason, nominal recession values have been used at some locations.

In locations where rock outcrops exist on a beach, it is anticipated that erosion will be limited to the section seaward of the rock extent. The maximum erosion prone area width in this area is given and is annotated with an asterisk (*).

The following discussion provides background information on the components making up the erosion prone area calculations. Kinhill Cameron McNamara (1994) also provide a general discussion on the determination of coastal buffer zone widths.

Short-term erosion

Storm erosion is caused by the exposure of the upper beach and dune to high wave conditions and elevated water levels. During normal conditions, the surf zone is limited to a position around the high water mark. However, the combined effect of storm surge, wave set-up and wave run-up allows storm wave energy to reach higher levels and usually results in the erosion of the upper beach and the transport of sediments offshore.

Generally, along a continuous beach the short-term erosion of the upper beach is balanced by a corresponding accretion in the nearshore zone. During calmer conditions the sand is gradually moved back onshore and, in conjunction with aeolian processes, rebuilds the upper beach.

The effects of cross-shore erosion can often be exacerbated during storm events by relative differences in longshore transport. Where the beach system is discontinuous, for example in the vicinity of a groyne or headland, these effects can be significant.

Numerical simulation of short-term beach erosion has been undertaken using the SBEACH modelling system developed by the United States Army Corps of Engineers Coastal Engineering Research Center (Larson and Kraus 1989). This model provides a semi-empirical approach to determine time-dependent cross-shore sediment transport processes for an arbitrary beach profile. SBEACH has been verified against a variety of physical model and field data and has been used extensively worldwide in planning studies and design of beach nourishment projects.

Guidance on the selection of the empirical parameters used for SBEACH input data is given by Larson and Kraus (1989). The sediment transport rate coefficients K and EPS are the primary calibration parameters. They were chosen using wave, water level and COPE (Harbour Beach) beach profile data for the tropical cyclone Joy event in 1990. The final parameter values used in the SBEACH modelling are stated in table 30.

Table 30 SBEACH parameter values

Description	Name	Value
spatial grid step (m)	DXC	2
time step (min)	DT	30
sediment transport rate coefficient ($m^{4/N}$)	K	2.0×10^{-6}
slope dependent transport rate coefficient (m^4/sec)	EPS	0.01
wave decay coefficient	KAPPA	0.06
foreshore slope	FSL	0.3
water temperature (°C)	TEMPC	27
depth corresponding to the land-ward end of the surf zone (m)	DFS	0.2
median grain size (mm)	D50	site-specific

The boundary conditions required for SBEACH modelling consist of a pre-storm beach profile and a time series of water levels and wave conditions. Typical hydrographs of wave height and water level were developed using predicted tide data and information from various numerical modelling studies. Wave periods and directions were determined from the analysis of recorded and hindcast extreme waves at the Bailey Islet site.

Peak design storm values were selected from the information on joint probabilities of waves and water levels. The approach is similar to that taken in previous studies, using the following criteria:

- the design storm tide level is considered more critical to the overall sensitivity of results than the design wave height;
- a design water level condition is chosen such that there is an estimated 40 percent chance of being equalled or exceeded over a 50-year planning period;
- assuming a Poisson distribution of occurrences of extreme events, the design water level condition corresponds to a 100-year average return interval (ARI);
- the adopted 100-year ARI storm tide level for the Mackay area is 4.1m AHD;
- for the purposes of generating water level hydrographs, the storm tide is assumed to comprise a 1.8m storm surge in conjunction with a 2.3m AHD tide (corresponding to mean high water springs); and
- the median extreme wave height (50 percent non-exceedance) corresponding to the 100 year ARI water level is chosen from the joint probability analysis. For a location offshore from Mackay, this Hsig value is 5.2m.

SBEACH modelling was undertaken for 10 locations in the study area (figure 52 provides an example of an SBEACH model run at Harbour Beach showing the pre- and post-storm beach profile). Results for storm erosion of the 4.6m AHD contour are provided in table 31. The 4.6m AHD contour corresponds to the design storm tide water level plus the typical wave run-up level.

The SBEACH model runs for the area between Bakers Creek and the Pioneer River show that the dunes are likely to be overtopped by the design storm. The simulated recession at the 4.6m AHD level is computed to be a relatively small value, typically in the order of 5m. The actual effect is estimated to be a recession of 30m, i.e. the width of the dune, due to overtopping. A storm erosion value of 30m has therefore been adopted for this section.

Dune scarping

A dune scarping component is included in the erosion prone area calculation to allow for slumping of the dune above the total water level of 4.6m AHD. It is assumed that the dunes will slump to a 1:3 slope (figure 53). As the dunes in the Mackay region vary in height from about 5m AHD to more than 15m AHD, the values adopted for the dune scarping component D are typically in the order of 5 to 20m.

Table 31 Storm erosion results, SBEACH (refer figure 32 for profile locations)

	Survey profile	Shoreline (4.6m AHD contour) (m/a)	Volume to 0m contour (m^3/m/a)
Bakers Creek–Shellgrit Creek	MAC108	4.6	not applicable
Far Beach	MAC108	4.6	not applicable
Town Beach	MAC112	5.1	not applicable
East Point	MAC118	25.3	35.9
Harbour Beach south	MAC122	15.1	16.1
Harbour Beach north	MAC134	8.5	49.8
Lamberts Beach	MAC137	25.9	165.5
Blacks Beach north	MAC159	16.0	128.9
Eimeo Beach	MAC167	7.3	0.3
Bucasia Beach	MAC178	15.3	41.6

Coastline recession

Coastline recession can be the result of long-term geological processes such as sea-level rise, or medium-term effects associated with the natural variability of coastal systems such as low frequency changes in the storm wave climate and fluctuations of river entrances.

Assessment of continuing erosion trends is generally undertaken using analysis of hydrographic survey data and aerial photography in conjunction with a review of the local geomorphology. The objective is generally to determine the maximum extent of recession that may occur in a 50 year planning period. In the case of a medium-term variability, the maximum recession may be reached before the end of the period.

Long term shoreline changes may result in a stable coastline, however current evidence may indicate that a particular beach is eroding or accreting. In situations where the beach is stable or accreting, a nominal long term erosion component has been adopted.

Where sufficient data are available, a sediment budget may be calculated to determine a volumetric loss (or gain) of material. A sediment budget deficit is converted into a horizontal recession through a linear relationship based on the simplified geometry of the beach profile (figure 54).

Based on the assumed profile, the annual erosion quantity can be related to the annual recession by the following relationship:

$$Q_e = (R \times h_1) + 0.5\,(R \times h_2)$$
$$= R\,(h_1 + 0.5h_2)$$
$$\therefore R = Q_e / (h_1 + 0.5h_2)$$

where Q_e = erosion quantity (m³/m/a)

h_1 = height of frontal dune above break in profile (m)

h_2 = depth below break in profile at the point where no changes occur (m)

R = long-term erosion rate (m/a)

This approach assumes that the volumetric changes are accommodated evenly along the beach. In reality, the coastline planform is affected in a complex way depending on the geological controls and the rates of sediment transport. In some cases, useful information can be gained from a coastline model that simulates the behaviour of beach systems subject to variable sediment supply.

A coastline model was established for Harbour Beach using Unibest CL+ (version 5.01) (Delft Hydraulics 1999) to assess the downdrift effects of the harbour walls and the sand extraction activities. Although the modelling approach is limited by a number of assumptions, the model provides a good indication of potential future changes for the section of Harbour Beach north of the walls. The application of this model is discussed below.

The long-term behaviour of some coastal sections is too complex to be represented by the Unibest CL+ model. The processes at Far, Town and Blacks Beaches are affected by cross-shore sediment transport, which cannot be represented in a one-line model. In these cases, estimates of long-term changes have been derived from an analysis of historical variations (table 32 provides the results of the analysis of potential coastline recession within a 50 year period).

Figure 52 SBEACH results for Harbour Beach (MAC122)

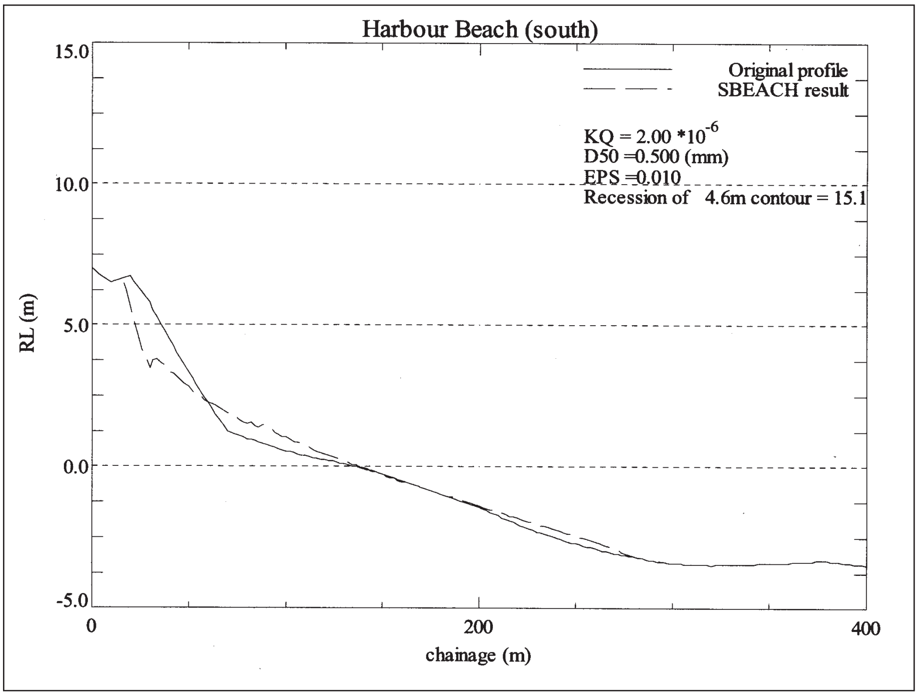


Figure 53 Dune scarp component of coastal recession

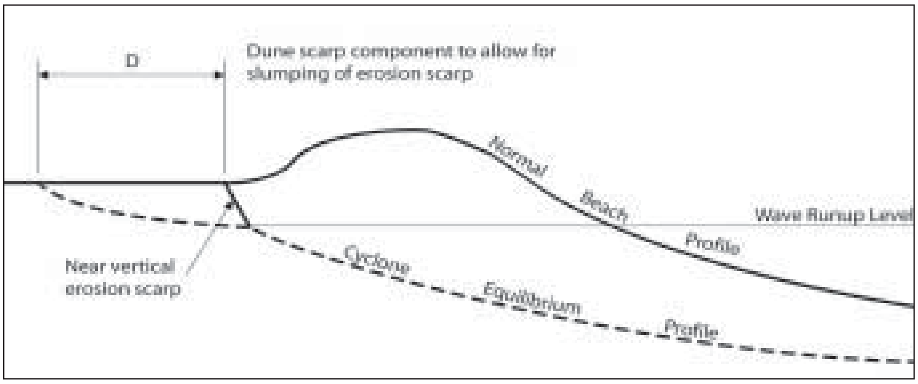


Figure 54 Horizontal recession for Blacks Beach

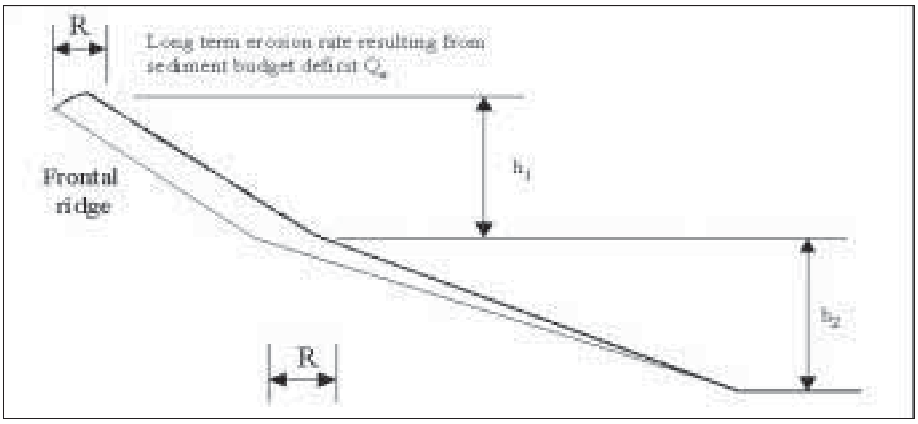


Table 32 Estimates of potential long-term coastline recession

Location	Coastline recession in 50 years (m)	Comment
Bakers Creek–Shellgrit Creek	20	based on historical fluctuations
Far Beach	50	based on present recession rate
Town Beach	10	nominal value
Harbour Beach south	10	nominal value
Centre of Harbour Beach north	80	derived from coastline model
Lamberts Beach	35	derived from coastline model
Blacks Beach south	20	based on historical fluctuations
Blacks Beach north	40	derived from historical coastlines
Eimeo Beach	10	based on present recession rate
Bucasia Beach	10	nominal value

Sea-level rise due to climate change

The assessment of coastline recession associated with climate change-induced, sea-level rise has been calculated separately from other estimates of coastline recession.

The potential impacts of climate change on the incidence of severe storms over the 50-year planning period are difficult to quantify. Even modest changes in tropical cyclone frequency and intensity would be difficult to separate from the natural variability. Due to the uncertainty of likely changes, no additional examination of the effects was undertaken as part of this study.

At the time of writing, the best estimate of projected global sea-level rise over the 50-year planning period is a value of 0.2m although estimates range up to 0.5m (figure 15). The Beach Protection Authority has adopted a more conservative value of 0.3m to assess the potential impacts of sea-level rise.

The Bruun Rule (Bruun and Schwartz 1985) is commonly used to determine indicative rates of recession for sandy beaches subject to sea-level rise. The calculation assumes that the beach maintains a dynamic equilibrium profile that is directly related to the mean sea-level. Thus there will be an increase in the level of the nearshore seabed in response to the increase in mean sea-level. Accordingly, an erosion of material from the upper beach maintains the equilibrium beach profile.

The formula for the Bruun Rule is a simple continuity relationship where the volume associated with the horizontal recession of the coastline is equal to the volume associated with the vertical increase in the bed level over the active beach profile. This is described by the following equation:

$$G \times Z = a \times B$$

where G is the recession associated with sea-level rise

Z is the vertical extent of the active profile

a is the sea-level rise

B is the width of the active profile

The active profile is considered to extend from the top of the primary dune to the depth of closure, which is the seaward limit of significant cross-shore sediment transport. The closure depth throughout the Mackay region has been derived from consideration of wave climate and sediment properties. The adopted value for beaches in the Mackay region is typically −10m AHD.

Results of the analysis of potential coastal recession associated with sea-level rise for the cases where the Bruun Rule can be applied are provided in table 33.

In many cases, the effects of sea-level rise on the coastal alignment are more complex than that described by the equilibrium profile approach of the Bruun Rule and the overall sediment budget needs to be taken into account. Complicating factors include:

- the sediment sink effects of estuaries and embayments;
- the significant cross-shore processes occurring on the tidal flats; and
- the supply of sediments from the Pioneer River.

The common factor is the assumption that the nearshore seabed level will accrete in response to an increased mean sea-level. This is also the basis of the Bruun Rule.

Even where no recession due to profile adjustment is likely to occur, the rise in water level will cause the shoreline to move up the profile. There will therefore be a general landward movement of the wave run-up limit, the line of vegetation and the toe of the foredune. The recession in this case is simply determined from the foreshore slope.

Table 33 Potential coastal recession associated with sea-level rise

Location	Survey profile	Depth of closure (AHD)	Coastal recession (m)
Bakers Creek–Shellgrit Creek	MAC104	0 m[a]	5
Far Beach	MAC108	1 m[a]	14
Illawong Park	MAC112	0 m[a]	21
Harbour Beach south[b]	MAC122	−10 m	20
Harbour Beach north	MAC134	−10 m	7
Lamberts Beach	MAC137	−10 m	9
Blacks Beach north	MAC159	−3 m[c]	21
Eimeo Beach	MAC167	−7 m	37
Bucasia Beach	MAC179	−6 m	13

a A modified depth of closure has been used for beaches fronted by wide tidal flats. The discussion in the coastal management section provides further details.

b The section of Harbour Beach adjacent to East Point is influenced by the onshore transport of sand from the Pioneer River entrance delta. The likely climate change recession value in this section is zero.

c The Blacks Beach profile is influenced by nearshore sand shoals that are considered independent of the beach system.

Response of tidal flats to sea-level rise

The assumptions of the Bruun Rule are generally not simply applied in the case where the beach is part of a system of wide tidal flats. In this case the behaviour of the beach is not completely connected with the tidal flats and the simple assumption of a profile adjustment across the entire profile cannot be applied. This is of importance in the Mackay region because of the prevalence of extensive tidal flats throughout the area. The calculation of the G component for the erosion prone area calculations for coastal sections that include tidal flats requires an estimate of a modified depth of closure. This is discussed further in the following chapter.

Within the Pioneer River estuary, a sea-level rise associated with the greenhouse effect could result in a corresponding net accretion of the river bed throughout the tidal reaches. While the system response would be affected by the present-day morphological behaviour of the river, it is likely to result in some reduction in the rate of export of sediments to the coast.

Storm tide hazard

In terms of risk of storm tide inundation, the Mackay region is one of the most vulnerable sections of the Queensland coast (Harper 1998). Numerical and statistical studies of the joint probability of storm surge and tide (BPA 1985) have indicated that potential storm tides in excess of 1m above the highest astronomical tide level (HAT) could occur on average once every 100 years.

Only two category four cyclones crossed the Queensland coast in the 20th century; one of these passed directly over Mackay in 1918. The resultant storm tide of approximately 2m above HAT (5.47m AHD) caused extensive flooding and damage to infrastructure. The storm tide flooding and the following freshwater flood in the Pioneer River contributed to the loss of 31 lives.

Because of the low-lying nature of many parts of the region, a number of residential areas are prone to coastal flooding (figure 55 shows the indicative area south of the Pioneer River that would be affected by a storm tide of 5m AHD). The coastal areas of South Mackay and East Mackay are clearly at risk from storm tide inundation.

Management of coastal areas, particularly the dune systems, is important to minimise the hazard of storm tide inundation. The maintenance of a well-vegetated dune system provides a natural barrier to extreme water levels and helps to absorb storm wave energy. This is particularly important at Town and Far Beaches.

Coastal management options

In some isolated cases within the Mackay region, property and infrastructure are threatened by coastal erosion. This is primarily the result of poor land use planning and usually can be attributed to a limited understanding of natural coastal processes at the time the land use decisions were made. Often such decisions were made in the order of 50 to 100 years ago. The appropriate management responses depend on the nature of the erosion and, ultimately, the overall cost.

Financial responsibility for protecting private property rests with the property owner. In cases where public assets, including beach amenities, are threatened, the local government is responsible. Some beach protection works carried out by local governments and approved by the Environmental Protection Agency normally attract a State Government subsidy.

Management options that can be used to protect properties from coastal erosion include:

- retreat through the acquisition of land or relocation of infrastructure;
- beach nourishment or beach scraping;
- dune conservation works;
- sand bypassing systems to ensure that natural sediment supply continues across artificial barriers;
- protective structures such as seawalls;
- beach control structures such as groynes, or offshore breakwaters; and
- configuration dredging to influence tidal flows and wave transformation patterns.

A number of coastal protection works have been undertaken in the Mackay region, primarily to protect freehold property and public infrastructure from coastal erosion. Rock walls have been constructed along open coast sections of Far, Town and Blacks Beaches. Lower-grade rock revetments have been constructed on the lee side of the major headlands, Slade Point, Dolphin Heads and Shoal Point. In many cases, although successful in reducing coastline recession, these walls have significantly affected adjacent beaches.

Retreat option

The option of removing or relocating infrastructure back from the threat of coastal hazards accords with the Environmental Protection Agency's policy of establishing coastal buffer zones. Assuming sufficient width is allocated to allow for the natural fluctuation of the coastline, this option is often the most cost-effective over the long term as it requires little continuing maintenance.

In cases where freehold or leasehold properties are adjacent to the high water mark, acquisition can have the added benefit of improving public access to beaches. Removing or relocating dwellings back from the beachfront can also be effective in reducing storm tide hazard.

Figure 55 Area south of Pioneer River affected by 5m AHD storm tide

The retreat option is generally expensive and is sometimes unpopular with landowners, but in isolated cases a full or partial acquisition may be the only realistic solution. Where properties are of sufficient size, it may be possible to relocate buildings and other improvements landward within the property.

Beach management

A number of options are available to maintain beach systems as a natural buffer against short-term erosion and storm tide flooding. Where specific upgrading of beaches is required, the Environmental Protection Agency generally favours beach nourishment as the most effective option.

Beach nourishment involves the mechanical placement of sand that is usually sourced from inactive sand reserves either offshore or on land. Sand may be placed directly on the upper beach or in the lower part of the beach profile using a technique known as nearshore nourishment. Nourishment works generally require the use of dredges and other expensive equipment. Costs can range from the order of $5/m^3 to more than $30/m^3, depending on the type of equipment required, the source of the nourishment sand and the quantity of sand involved. In addition, a nourishment maintenance program is usually required over the longer term.

An alternative form of beach nourishment is the mechanical movement of sand from one part of the beach system to another, commonly known as sand scraping. This can be undertaken relatively cheaply using conventional earthmoving equipment. While the technique is limited in that the overall beach volume does not change, it is useful in some situations to build up the upper beach sections using sand from nearshore areas.

Sand scraping is a useful technique in regions such as Mackay, where the large tide range provides good access to nearshore areas at low water. The technique is also likely to be cost-effective because of the relatively slow changes in coastal morphology through much of the region.

Continuing dune conservation works to maintain the sand reserve in the dune system are an essential component of coastal management. The dunes are generally the primary barrier against storm tides and are effective in absorbing wave energy during storms. Typical dune conservation works include revegetation and the construction of pedestrian control fences and access tracks.

Where littoral longshore transport is interrupted by works such as river entrance training walls, dredged channels or breakwaters, an artificial sand bypassing system may be beneficial in preventing downdrift erosion. Bypassing systems can take on a variety of forms and are usually based on hydraulic or mechanical sand-pumping plant. Such systems are generally quite expensive to construct and operate. As they are usually required only to compensate for the interruption of littoral processes by large-scale coastal infrastructure, the implementation of artificial sand bypassing systems should be considered in the overall costs of the asset.

Coastal protection works

Seawalls or revetments are commonly used to protect property from coastal erosion and are often constructed in response to a short-term storm erosion event. The effect of such hard structures in a dynamic beach system is to locally accelerate sediment transport processes, often leading to reduced beach levels and erosion on adjacent beaches. Thus the original erosion ‘problem’ is solved but the beach itself may lose its value as a coastal protection or recreational asset.

In cases of continuing coastline recession, a seawall does not halt the underlying erosion processes and can sometimes exacerbate the situation. In these cases, the beach levels in front of the wall are steadily lowered, eventually leading to stability problems for the wall itself.

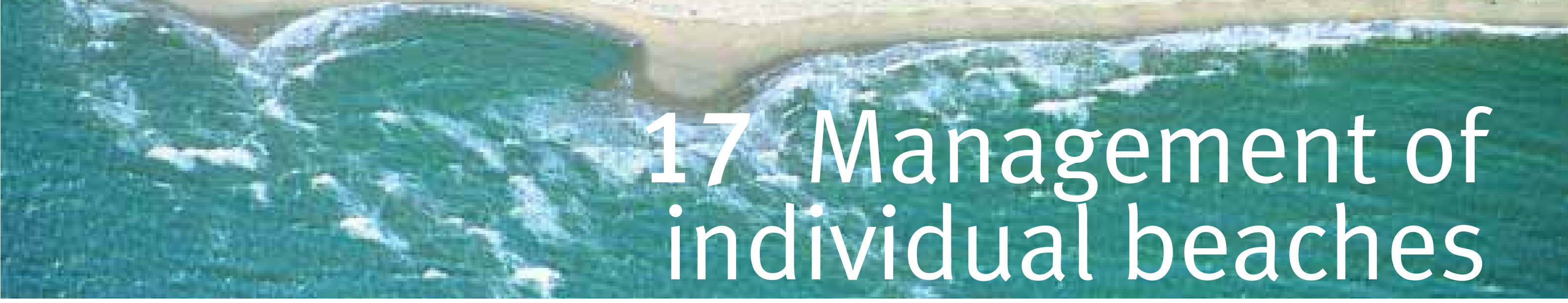
Properly engineered seawalls are an effective means of protecting property from extreme events, but they are relatively expensive and require continuing maintenance costs. Often landowners have little option but to protect their property from persistent erosion. In these cases, it is generally preferable that walls are constructed on, or landward of, the property boundary and along an alignment consistent with structures on adjacent properties. Ideally, this alignment should closely approximate the natural (eroded) coastline position.

Rock walls built in response to a severe short-term erosion event are often of a substandard design and incorporate inadequately sized armour units. These walls typically require significant continuing maintenance and may be subject to a high risk of failure during the next extreme event. In the worst case, such walls can contribute to a false sense of security when property owners continue to place high-value structures at significant risk of severe damage or complete loss.

Control structures such as groynes and offshore breakwaters can be used to influence the behaviour of a particular section of beach. When properly designed and constructed, these structures are usually successful in widening a beach and thus improving recreational amenity and coastal protection. The accretion of sand caused by these control structures is normally associated with an accompanying erosion of an adjacent area. The downdrift erosion behind a groyne is a well-known example of this problem. Control structures are often used in conjunction with beach nourishment works to minimise continuing maintenance requirements.

Where nearshore tidal channels occur close to the coastline, the stability of the upper beach can be affected. This is most likely to be in the vicinity of a tidal inlet. Often the patterns of tidal flows fluctuate in velocity and location, and can lead to recession of the adjacent shoreline. The artificial diversion of tidal flows through configuration dredging can be used to reduce the impacts of this type of behaviour. The costs and the relative success of these types of works are highly variable and are strongly dependent on the designer’s understanding of the key coastal processes.

Town Beach seawall



17 Management of individual beaches

Introduction

Details of studies of coastal processes for the Mackay region are presented in previous chapters. The objective of quantifying these coastal processes is to provide an understanding of the behaviour of the coastal systems and to develop appropriate coastal management strategies. The purpose of this chapter is to present the main findings of the study in relation to individual beaches with reference to the coastal management issues discussed in the previous chapter.

Bakers Creek to Shellgrit Creek

The coastal section between Bakers Creek and Shellgrit Creek has only limited development infrastructure and comprises mainly reserves (figure 56 summarises the land tenure). The Mackay City Strategic Plan shows a designation of *open space and recreation*.

The coastal section is formed entirely from Holocene depositional processes. A system of dunes of low to medium height has developed at the shoreline, backed by a relatively low-lying backshore area. This area is drained by a series of small shore-parallel creeks, including Shellgrit Creek, which flows out across the intertidal flats at a point approximately midway between Bakers Creek and the Pioneer River.

Erosion prone area widths

The calculation of erosion prone areas has been reviewed following techniques established by the former Beach Protection Authority (refer to Coastal Management chapter). The breakdown of erosion prone area width components is given in table 34). Based on these values, the existing erosion prone area width of 80m is considered to be appropriate and is unchanged (figure 56 shows the widths of erosion prone areas for this coastal section).

Table 34 Erosion prone area width calculations, Bakers Creek to Shellgrit Creek

Parameter	Value (m)
Long term erosion component ($N \times R$) (based on historical fluctuations)	20
Short term erosion component (C) (estimated)	30
Recession related to the sea level rise associated with the Greenhouse effect (G)	5 5
Dune scarp component (D)	5
Calculated width	80
Existing width	80

Effects of sea-level rise

The response of the system of tidal flats in Sandringham Bay and south of the Pioneer River to sea-level rise is difficult to evaluate. Detailed modelling of long-term morphological changes is complex and is beyond the scope of the present study; however, estimates can be made of the likely response of the upper beaches.

The system response to an expected sea-level rise associated with the greenhouse effect of 0.3m over the next 50 years includes:

- the Bakers, Sandy and Alligator Creek estuaries acting as a sediment sink – i.e. there will be a net accumulation of marine sediments;
- an increase in the level of the intertidal flats; and
- a reduction in the width of the intertidal flats in Sandringham Bay.

In general, a delta formation that has reached an equilibrium configuration will tend to reduce in area in response to a sea-level rise as the estuary draws sediment from the coastal system. This is expected to occur in Sandringham Bay. The Bakers, Sandy and Alligator Creek systems are not thought to be exporting beach material-size sediments to the coast and would act as sediment sinks. The seaward edge of the tidal flats is likely to recede as elevated water levels move sediments onshore where they are trapped in the estuary and delta system. The tidal flats would tend to maintain a minimum plan area as the recession would be limited by the sheltering effect of the Dudgeon Point and Hay Point headlands.

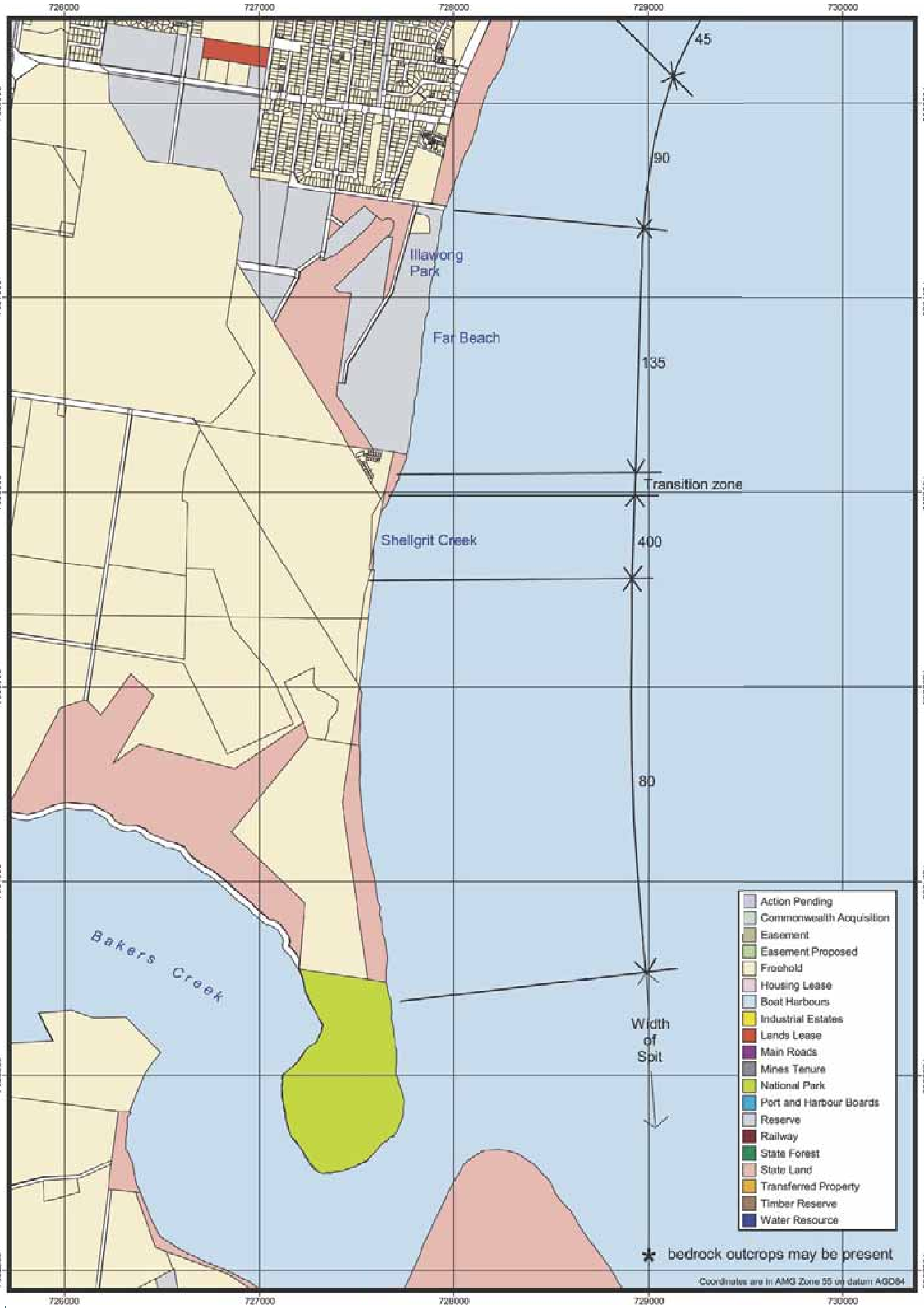
As depicted in figure 38, the tidal flats north of the Bakers Creek entrance are characterised by onshore wave-driven sediment transport, which is approximately balanced by the net longshore transport close to the shoreline. This onshore sediment transport would be expected to continue following a sea-level rise, although a significant proportion of sediment will be retained on the tidal flats as the bed level increases proportionally to sea-level rise. The net rate of sand reaching the upper beach system would therefore be reduced, and as the net longshore transport would remain unchanged the upper beach would erode in response.

Assuming that the nearshore sea bed level increases at the same rate as the rise in mean sea-level, the rate of accumulation on the tidal flats per metre length of coastline is ($a/N \times B$) m^3/m/a (where a/N is the rate of sea-level rise). For an indicative width (B) of 2.5km, this rate is therefore in the order of 15m^3/m/a, which is significantly higher than the estimated present rate of onshore sediment transport. It is likely that some erosion over parts of the profile will occur and that the edge of the tidal flats will recede.

Sea-level rise will cause some profile redistribution to occur as described by the Bruun Rule. However, it is unrealistic to assume that sand from the upper beach will be distributed across the entire profile, which is of the order of 2 to 3km wide. It is predicted that this will be limited to the upper part of the profile and SBEACH model simulations show that during a storm event with a water level corresponding to MHWS the width of the active profile is in the order of 100 to 150m. For the purposes of estimating a value for G, shoreline recession associated with sea-level rise, a depth of closure of 0m AHD has been adopted. The Bruun Rule has been applied to this coastal section using this modified depth of closure (table 33).

Based on the assumption of equilibrium nearshore beach profiles, an anticipated shoreline recession of 5m associated with sea-level rise associated with the greenhouse effect along the coastal section between Bakers Creek and Shellgrit Creek has been estimated over the next 50 years.

Figure 56 Land tenure and revised erosion prone area widths, Bakers Creek to Town Beach



Town Beach and Far Beach

The coastal section between Shellgrit Creek and the Pioneer River is adjacent to the Mackay city centre and has extensive areas of residential and tourism development (figures 56 and 57 provide a summary of land tenure). The area is also important to the local community for recreation, and a number of parks and reserves provide very good public beach access.

East Mackay and South Mackay are characterised as relatively low-lying land fronted by a system of narrow dunes. Many of the residential areas have been artificially reclaimed and filled as part of a progressive expansion of urban land use for mainly residential purposes. Much of the East Mackay landform is relatively recent in geological terms, and once formed part of the Pioneer River outer estuary.

Erosion prone area widths

A review of the erosion prone area widths has been undertaken in accordance with the former Beach Protection Authority's recommended procedure (figures 56 and 57 summarise the recommended revisions).

The erosion prone area width at the southern end of Far Beach in the vicinity of Shellgrit Creek has been increased from 80 to 400m. This is recommended to allow for the increased potential for long-term recession associated with the fluctuations in the creek entrance.

Far Beach is currently undergoing a continuing trend of erosion due to the changes in the Pioneer River entrance. The primary deposition zone of sediments transported from the Pioneer River prior to 1898 was approximately midway along the Far Beach section. The present configuration of the river training wall, established approximately 100 years ago, has shifted the primary zone of deposition to the area south-east of the entrance in the lee of Flat Top Island. This has resulted in a reduction of onshore sediment transport to Far Beach.

Table 35 Erosion prone area width calculations, Shellgrit Creek to Illawong Park

Parameter	Value (m)
Long term erosion component (*N* x *R*) (based on current recession rate)	50
Short term erosion component (*C*) (estimated)	30
Recession related to the sea-level rise associated with the Greenhouse effect (*G*)	14
Dune scarp component (*D*)	5
Calculated width	135
Existing width	80

The components of the erosion prone area width in the section between Shellgrit Creek and Illawong Park (including the rock wall) are detailed in table 35. Using these values the recommended erosion prone area width is 135m, increased from the existing value of 80m.

The erosion prone area width between the northern end of Illawong Park and the Town Beach rock wall is calculated in table 36. Using these values, the recommended erosion prone area width is 90m, an increase from the existing value of 80m.

Table 36 Erosion prone area width calculations, Illawong Park to Town Beach rock wall

Parameter	Value (m)
Long term erosion component (*N* x *R*) (nominal)	10
Short term erosion component (*C*) (estimated)	30
Recession related to the sea-level rise associated with the Greenhouse effect (*G*)	21
Dune scarp component (*D*)	5
Calculated width	90
Existing width	80

Sea-level rise associated with the greenhouse effect is expected to increase the rate of shoreline recession over the next few decades. At the northern end of Town Beach the present rate of accumulation is estimated to be 5000m^3/a, which is equivalent to a uniform increase in bed levels of 8mm/a. This rate would approximately balance the requirements of sea-level rise, resulting in a negligible net effect and the present accretion trend will be halted.

The calculation for the Town Beach section, given in table 37, for the erosion prone area width therefore contains nil recession associated with Greenhouse sea-level rise due to its offset against the anticipated accretion occurring in the area. Using these values, a reduction to 60m from the existing erosion prone area width of 80m is determined.

Table 37 Erosion prone area width calculations, Town Beach

Parameter	Value (m)
Long term erosion component (*N* x *R*) (nominal)	10
Short term erosion component (*C*) (estimated)	30
Recession related to the sea-level rise associated with the Greenhouse effect (*G*)	0
Dune scarp component (*D*)	5
Calculated width	60
Existing width	80

Illawong Park rock wall

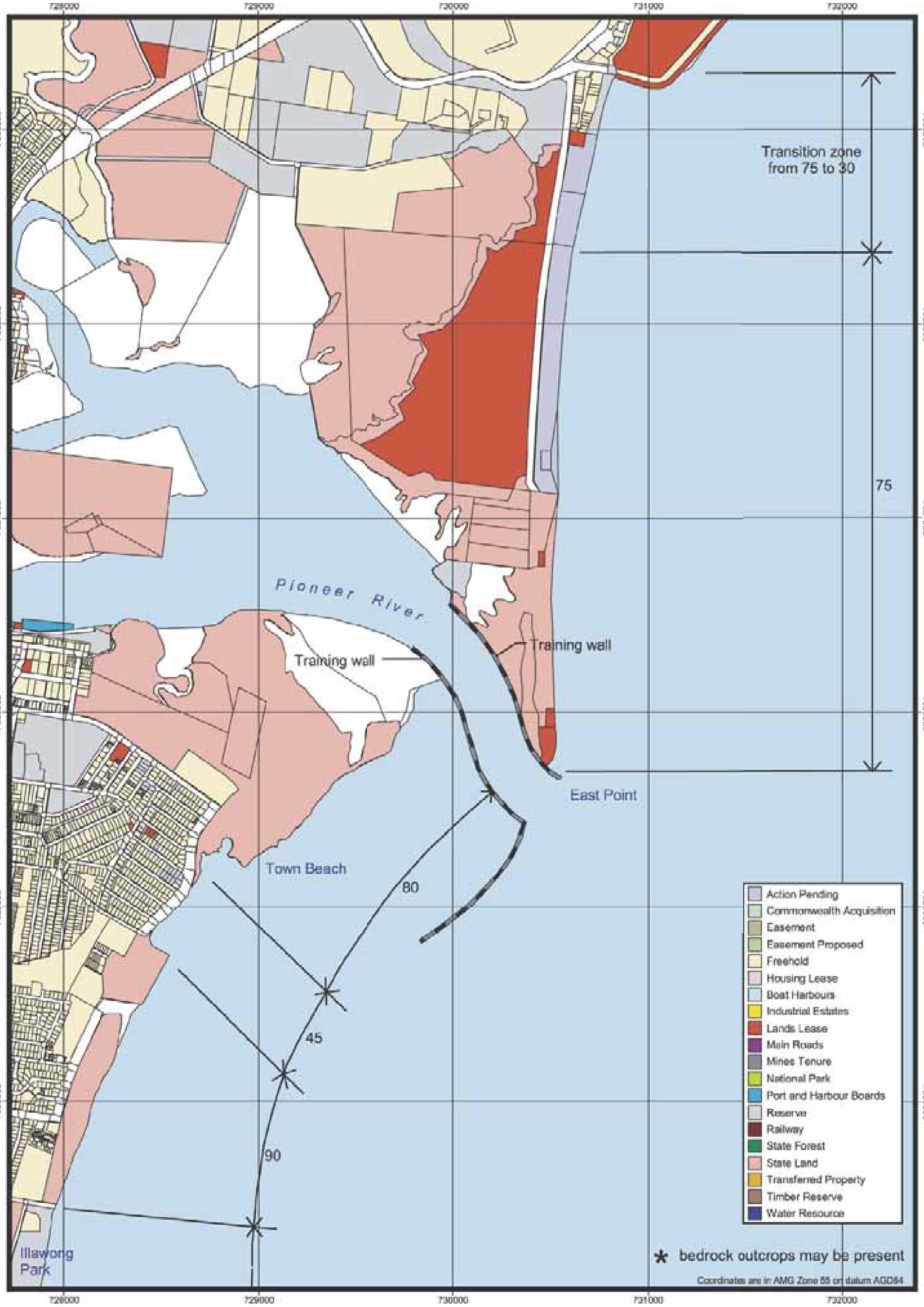
A rock wall has been constructed seaward of the Illawong Park recreation reserve to counter the erosion trend at Far Beach. Associated with the rock wall are reduced beach levels and recession of the adjacent beaches due to terminal effects. The wall is also prone to damage during severe storm events.

The continued maintenance or upgrading of the Illawong Park rock wall is not recommended. Ideally, the wall should be removed and existing structures in the park be relocated landward to allow the beach to fluctuate naturally.

Alternatively, some beach nourishment or scraping works could be undertaken to improve the upper beach and the general amenity of the area. Periodic placement of sand in front of the wall would also improve its ability to withstand storm wave attack and reduce maintenance requirements.

Rock wall at Far Beach.

Figure 57 Land tenure and revised erosion prone area widths, Town Beach to Harbour Beach south



Town Beach coastline

Survey and aerial photography data indicate a low rate of accretion at the northern end of Town Beach. Sediments deposits in the vicinity of the training walls are largely due to the effects of the walls and could be used as a source of beach nourishment sand. The suitability of this material would depend on the silt content and its use would be subject to an examination of associated environmental impacts. Due to the low rates of accretion, continuing sand extraction is considered inappropriate.

The development of residential areas in East Mackay has included reclamation works and alterations to the natural drainage system, including:

- the excavation of a large area on the tidal flats adjacent to the reclamation on Binnington Esplanade;
- the subsequent construction of a rock wall to protect the road;
- the diversion of stormwater flows southward to Shellgrit Creek; and
- the associated closure of the small tidal creek entrance, locally known as Pothole Creek, at the southern end of Town Beach.

The closure of Pothole Creek has resulted in localised changes to the nearshore bathymetry at the southern end of Town Beach. The volume of sand previously associated with the ebb tide delta is slowly migrating onshore and northward towards the rock wall and extraction site off Town Beach. This is expected eventually to help form a sandy beach at the base of the wall and thus improve the general amenity of the area.

It is recommended that beach nourishment or scraping be undertaken to fill the dredged hole and build up the upper beach in the vicinity of the Binnington Esplanade shorefront. Ideally, the nourishment should completely cover the rock wall, reducing its detrimental effects while retaining its coastal protection attributes. These works would also improve the structural integrity of the wall itself.

Potential sources of sand include:

- the sandbank immediately to the south of the rock wall;
- the area of natural reclamation to the north of the site adjacent to the training walls (depending on suitability); or
- the outer section of the ebb tide delta of the Pioneer River entrance.

Storm tide hazard

The narrow dune system and the relatively low-lying backshore area make the Far Beach and Town Beach section vulnerable to storm tide inundation. This is exacerbated by the continuing trend of erosion. The impacts of the 1918 storm tide event was focused primarily on the East Mackay area and it is likely that a similar event would pose a severe hazard through East Mackay and South Mackay. It is recommended that the dune system along Far Beach and Town Beach is carefully managed and enhanced where possible, to provide a protective buffer against potential storm tide inundation.

The existing development (Illawong Beach Resort) adjacent to the Shellgrit Creek entrance is located in the erosion prone area and is vulnerable to storm tide inundation. It is recommended that the density of development should not be increased in this area.

Pioneer River entrance

The observed behaviour of the Pioneer River entrance is closely linked to the continuing output of sediments from the estuary and the effects of the training wall structures on the patterns of sedimentation.

Despite the high rates of commercial extraction of sand and gravel from the tidal reaches of the Pioneer River, the subtidal delta at the entrance is continuing to accrete at an estimated rate of 45,000m^3/a. The effects of the extraction operations and the influence of sea-level rise associated with climate change are expected to result in a gradual reduction of this growth rate.

The deeper sections of the delta between Flat Top Island and East Point are a potential site for commercial sand extraction, but its economic feasibility would need to be examined.

The training walls at the entrance to the Pioneer River, constructed over the period 1890 to 1905, have markedly altered the sediment transport processes. Before 1898, a long continuous sand spit extended from the present location of East Point towards the south-south-west. Sections of this spit would episodically break away in response to floods and storm events, and a proportion of the sediments would migrate onshore to feed Far Beach.

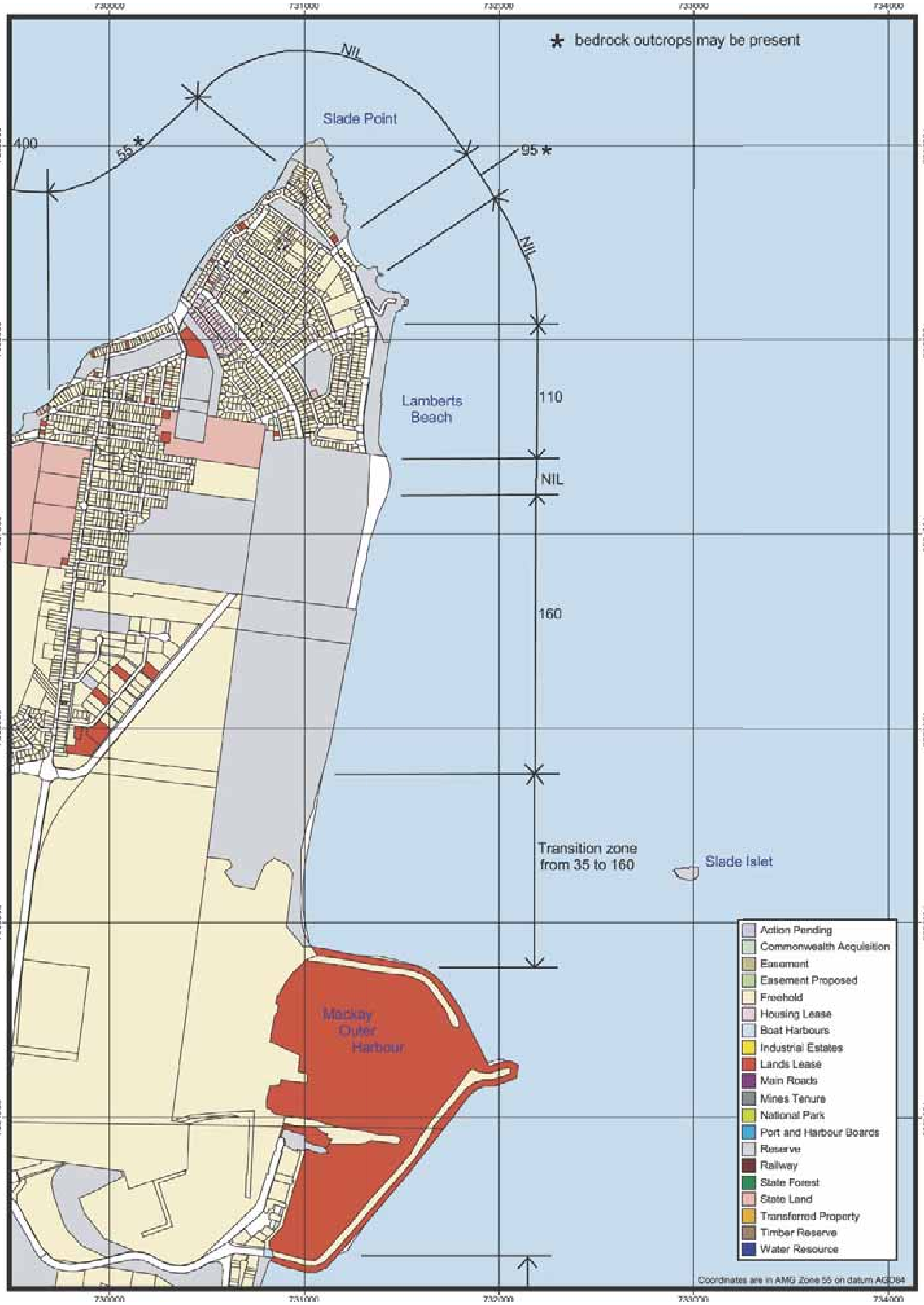
In its present configuration, the entrance has the appearance of a subtidal delta extending towards the south-east into the lee of Flat Top Island. It is anticipated that the delta will form a partial tombolo with Flat Top Island over the next 50 years. This has potential implications for upstream flood levels in the Pioneer River.

The training works in the river entrance have effectively stabilised the configuration of the outer bar area. Although a worsening is predicted, the hydraulic efficiency of the entrance in its present configuration is better than the pre-1898 case. There is, therefore, no recommendation to alter the entrance training walls.

To improve estimates of the accretion rates and understanding of the behaviour of the Pioneer River entrance, an enhanced program of monitoring should be implemented. This would be in the form of detailed soundings over the area encompassing East Point, Flat Top Island and Town Beach. The use of newly developed remote sensing techniques could minimise costs. The capture of regular vertical aerial photography should continue and extend to a point seaward of Flat Top Island.

Extensive sand deposits occur at the mouth of the Pioneer River.

Figure 58 Land tenure and revised erosion prone area widths, Harbour Beach north to Slade Point



Harbour Beach and Lamberts Beach

Harbour Beach and Lamberts Beach form a contiguous coastal section from the Pioneer River entrance at East Point to Slade Point. The section is characteristic of an open coast beach, relatively exposed to the prevailing wave climate and the nearshore tidal currents. Before the construction of the harbour in 1935 to 1939, the beach alignment had formed in approximate equilibrium with the regular throughput of northward longshore sediment transport from the river entrance and the location of the bedrock headland of Slade Point.

The net longshore sediment transport rate at Harbour Beach is estimated to be 35,000m^3/a. This relatively high sediment supply combined with prevailing onshore winds has resulted in the formation of extensive dune fields more than 20m in height towards the northern end of the beach.

Until recently, the primary use of the Harbour Beach section was associated with the port. Large areas of the dunes in the central section of Harbour Beach have been cleared and levelled for port facilities and other industrial uses. North of the harbour, the extensive dune fields and backshore areas have been set aside as conservation reserves (figures 57 and 58 detail land tenure). High-density residential and tourism infrastructure has been established in the area south of the harbour. This has included an extension to the harbour basin for a small boat marina and the redevelopment of the community recreation facilities and the surf club. The remainder of the area is undeveloped at present however further residential and tourism development is proposed. Immediately behind the southern section is a system of tidal wetlands including Bassett Basin, a fish habitat area declared under the *Fisheries Act 1994*.

The formerly continuous coastal section between the Pioneer River entrance and Slade Point is now interrupted by the harbour walls. Small fillets of accretion can be seen immediately north and south of the walls and a marked trend of erosion has been observed along the northern section and Lamberts Beach. Only a very minor quantity is bypassing the harbour naturally.

The extent of the accretion on the southern side of the harbour is controlled by the volume of sand commercially extracted from the area, recently averaging about 45,000m^3/a. Interception of this sand is important to the operation of the port as it controls the potential sedimentation of the harbour entrance channel. The extraction is generally managed to minimise recession of the shoreline.

The coastline model of Harbour Beach also provides an estimate of the downdrift effects of longshore transport past Slade Point. As the centre of Harbour Beach north recedes and takes up more of a pocket beach alignment, the net northward longshore sediment transport rate will reduce. This has important implications for the stability of beaches further north, including Blacks Beach. The results indicate that the rate of sediment transport bypassing Slade Point will reduce by 3,000m^3/a over a 50 year simulation period.

Erosion prone area widths

A review of the erosion prone area widths has been undertaken (figures 57 and 58 summarise recommended revisions).

The components of the erosion prone area width in the section in the vicinity of East Point are contained in table 38. Note that the onshore transport of sediment in the nearshore area adjacent to the Pioneer River entrance will effectively offset any recession due to the sea-level rise associated with the Greenhouse effect.

Table 38 Erosion prone area width calculations, East Point

Parameter	Value (m)
Long term erosion component (*N* x *R*)	20
Short term erosion component (*C*) (estimated)	25
Recession related to the sea-level rise associated with the Greenhouse effect (*G*)	0
Dune scarp component (*D*)	10
Calculated width	75
Existing width	110

Accordingly, using these values the recommended erosion prone area width is 75m, reduced from the previous value of 110m.

Between East Point and a point 800m south of the small craft harbour, the recommended erosion prone area width is 75m, reduced from the previous value of 110m. This is shown in table 39.

Table 39 Erosion prone area width calculations, East Point to 800m south of the small craft harbour

Parameter	Value (m)
Long term erosion component (*N* x *R*) (nominal)	10
Short term erosion component (*C*) (estimated)	15
Recession related to the sea-level rise associated with the Greenhouse effect (*G*)	20
Dune scarp component (*D*)	10
Calculated width	75
Existing width	110

In the section immediately south of the harbour breakwater, the recommended erosion prone area width transitions from 75 to 30m. This calculation assumes a linear reduction of the values of both the long–term erosion (*N* x *R*) and the sea-level rise associated with the Greenhouse effect (*G*) components to zero at the breakwater. This is based on the observed trend of accretion in this area and assumes:

- the ongoing supply of sediments from the Pioneer River entrance is not interrupted; and
- the management of the extraction activities minimises the potential for recession of the shoreline from the present position.

Immediately north of the harbour breakwaters, the recommended erosion prone area width is 45m, reduced from the previous value of 110m (table 40). This value transitions to the Harbour Beach north erosion prone area width of 160m over a distance of 1000m.

Table 40 Erosion prone area width calculations, immediately north of the Mackay Harbour breakwater

Parameter	Value (m)
Long term erosion component (*N* x *R*)	0
Short term erosion component (*C*) (estimated)	9
Recession related to the sea-level rise associated with the Greenhouse effect (*G*)	0
Dune scarp component (*D*)	20
Calculated width	35
Existing width	110

The components of the erosion prone area widths over the remainder of Harbour Beach north are detailed in table 41. Using these values the recommended erosion prone area width is 160m, increased from the previous value of 110m.

Table 41 Erosion prone area width calculations, Harbour Beach north

Parameter	Value (m)
Long term erosion component (*N* x *R*) (derived from coastline model)	80
Short term erosion component (*C*) (estimated)	9
Recession related to the sea-level rise associated with the Greenhouse effect (*G*)	7
Dune scarp component (*D*)	20
Calculated width	160
Existing width	110

The recommended erosion prone area width of Lamberts Beach is 110m, identical to the existing value (table 42).

Table 42 Erosion prone area width calculations, Lamberts Beach

Parameter	Value (m)
Long term erosion component (*N* x *R*) (derived from coastline model)	35
Short term erosion component (*C*) (estimated)	26
Recession related to the sea-level rise associated with the Greenhouse effect (*G*)	9
Dune scarp component (*D*)	10
Calculated width	110
Existing width	110

Slade Point

Slade Point is a popular residential area with a significant number of properties located close to the coastline on both the eastern side of the headland and the western shoreline, as shown in figure 59. In the south western corner of Slade Bay, the topography shows a reduction in height towards the entrance to McCreadys Creek.

Slade Point Beach

Slade Point Beach is a small section of pocket beach perched on the rocky platform at the base of the eastern side of the headland. The high potential longshore sediment transport rate relative to the actual supply precludes the regular formation of a sandy beach, although this sometimes occurs under favourable conditions. The beach generally comprises rocky material in the form of gravel and cobble mixed with some sand.

Before the establishment of residential subdivisions on Slade Point, it is likely that an overland aeolian transport of sand existed behind the headland from Lamberts Beach to Slade Point Beach. This sand was probably also a source of supply to Slade Point Beach which has now been eliminated. The effect on Slade Point Beach is exacerbated by the general erosion trend along Harbour Beach north and Lamberts Beach caused by the blocking effect of the harbour walls.

The calculation of erosion prone area width for Slade Point Beach indicates a value of 100m (table 43). Given that the beach contains a relatively high proportion of cobbles and rocks, the existing value of 95m is considered acceptable and is unchanged.

Table 43 Erosion prone area width calculations, Slade Point Beach

Parameter	Value (m)
Long term erosion component (*N* x *R*) (nominal)	10
Short term erosion component (*C*) (estimated)	25
Recession related to the sea-level rise associated with the Greenhouse effect (*G*)	30
Dune scarp component (*D*)	10
Calculated width	100
Existing width	95

Slade Point and Slade Bay in the background.

Western coastline of Slade Point

The inshore section along the western shoreline of Slade Point comprises a rocky platform overlain with sand and mud. The fluctuations in the alignment of McCreadys Creek and the variability in sand supply from around Slade Point cause shoreline movements along this section. The volume of sand on the upper beach is dependent on the effects of high-energy wave events, which generate bursts of high short-term longshore transport. These result in episodic sequences of erosion and accretion followed by extended periods of little change. Due to the relative sheltering and the effects of McCreadys Creek, the shoreline variability is more noticeable at the western end of the beach.

A number of private landholders have constructed low rock walls to protect their properties against episodic erosion. Due to the reflective nature of these structures, sandy upper beaches are rarely established along their lengths. Where possible, further construction of these walls should be avoided, although it is recognised that continuing protection of public and private infrastructure is necessary. Rock walls should be constructed only on private property.

In some cases, the rock walls are critical for the protection of houses and other infrastructure. A review of the adequacy of these existing walls to withstand storm wave attack, along with the potential for overtopping during a severe storm should be undertaken to ensure the property owners are aware of the potential risk of failure and/or flooding.

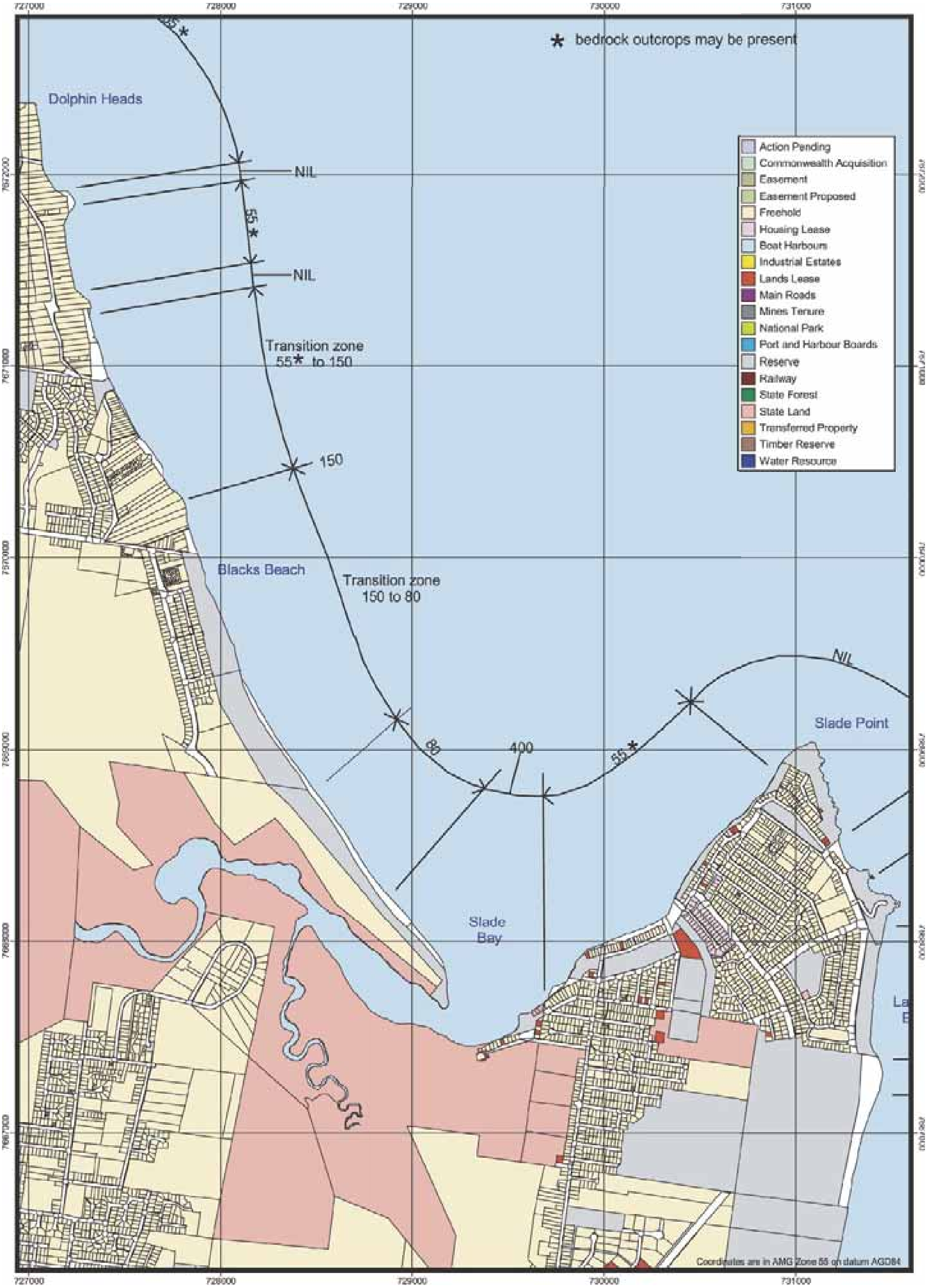
Overall trends in the available hydrographic survey data indicate that the volume of the tidal flats in this area is relatively stable and it appears that the embayment has reached an approximate equilibrium in geological terms. There is no clear evidence of a recent erosion trend.

The erosion prone area width for the section between Slade Point and McCready's Creek is 55m and remains unchanged (table 44).

Table 44 Erosion prone area width calculations, Slade Point to McCready's Creek

Parameter	Value (m)
Long term erosion component (*N* x *R*) (nominal)	10
Short term erosion component (*C*) (estimated)	20
Recession related to the sea-level rise associated with the Greenhouse effect (*G*)	5
Dune scarp component (*D*)	5
Calculated width	55
Existing width	55

Figure 59 Land tenure and revised erosion prone area width, Slade Point to Dolphin Heads



Blacks Beach

The northern section of Blacks Beach has become a relatively high growth area of Mackay City, with increasing areas of residential and tourism development. A number of new residential subdivisions have been established or are planned in the area, along with associated commercial developments such as hotels, restaurants and shopping precincts. The southern end of the beach comprises an extensive area of public reserve (figure 59 shows land tenure).

Erosion prone area widths

The components of the erosion prone area width for the southern section of Blacks Beach between McCready's Creek and a point opposite Anglers Parade is contained in table 45. Using these values the recommended erosion prone area width is 80m and remains unchanged.

Table 45 Erosion prone area width calculations, Blacks Beach (south)

Parameter	Value (m)
Long term erosion component (*N* x *R*) (based on historical fluctuations)	20
Short term erosion component (*C*) (estimated)	22
Recession related to the sea-level rise associated with the Greenhouse effect (*G*)	5
Dune scarp component (*D*)	10
Calculated width	80
Existing width	80

Widths of erosion prone areas have been assessed, taking into account the sediment transport processes and the likely influence of sea-level rise associated with the Greenhouse effect (figure 59). Since the continuing maintenance of the rock walls at the northern end of Blacks Beach is the responsibility of private landholders and cannot necessarily be guaranteed, the assessment doesn't take into account the present efforts to hold the line. Therefore erosion prone area widths do not take into account the effects of the rock walls.

The erosion prone area width for the northern section of Blacks Beach is calculated in table 46. The calculation includes an adopted value of 40m for the long term erosion component (*N* x *R*), based on the analysis of previous coastline changes.

Using these values the recommended erosion prone area width is 150m, an increase from the existing values which vary between 80 and 140m.

Table 46 Erosion prone area width calculations, Blacks Beach (north)

Parameter	Value (m)
Long term erosion component (*N* x *R*) (derived from historical coastlines)	40
Short term erosion component (*C*) (estimated)	16
Recession related to the sea-level rise associated with the Greenhouse effect (*G*) due to the reduction in sediment supply resulting from the accretion of the tidal flats in Slade Bay	21
Recession associated with profile re-adjustment related to the sea-level rise associated with the Greenhouse effect (*G*)	21
Dune scarp component (*D*)	10
Calculated width	150
Existing width	80

Effects of sea-level rise

The primary sediment transport path from Slade Point to Slade Bay is across the intertidal flats. The rise in seabed level in the deposition zone behind Slade Point will be supplied by the incoming sediment transport rather than by recession of the upper beach. The implication, however, is that the net downdrift supply to the centre of Blacks Beach will be reduced, and since the outgoing potential longshore transport rate at the northern end of Blacks Beach remains unchanged, there will be a generalised trend of recession.

The plan area of the Slade Bay tidal flats is approximately 200ha. The plan area geometry is controlled by the presence of the headland and the direction of the prevailing wave climate and is expected to remain relatively constant following a sea-level rise. Assuming the seabed rises in direct response to a 0.3m sea-level rise over 50 years, the rate of accumulation and therefore the net loss of sediment to the downdrift system would be in the order of 12,000m^3/a. This effect is likely to be seen between the centre and the northern end of Blacks Beach in the vicinity of the coastline bulge, which will recede in response to the reduced sediment throughput rate.

This is superimposed on the recession caused by profile readjustment as determined by the Bruun Rule.

In the absence of the rock walls at Blacks Beach, the net loss of sand would be made up from a continuing erosion of the dunes and the coastline would recede until the alignment accommodated the lower sediment transport rate. Over a coastline length of 2km, the average rate of recession is 6m^3/m/a. Using the schematised beach profile for Blacks Beach given in figure 54, this converts to a recession rate of 21m over 50 years.

Rock walls

Continued maintenance of the Blacks Beach rock walls would protect the present coastal alignment, although considerable erosion would be expected to occur on the beaches adjacent to, and seaward of the walls. Additional works would be required to strengthen the toes of the walls and their flanks as the adjacent coastline recedes. Some enhancement to the structural quality of the walls, possibly including increased crest levels, may be necessary due to an increased exposure to storm wave attack caused by lowered beach levels.

During a storm, the majority of waves break seaward of the upper beach. The depth of water at the base of the wall therefore generally limits the largest waves impacting on the rock walls. This, in turn, is controlled by the absolute water level and the beach levels. A review of the capacity of the existing walls to withstand severe waves, along with the potential for overtopping during an event with a 100 year return interval, should be undertaken and should include a consideration of anticipated conditions.

Due to the potential for continuing shoreline recession, it is preferred that new development should not be established within the erosion prone area. The location of high-density land uses such as holiday apartments should be carefully considered. Significant improvements to existing residential and commercial infrastructure should also be avoided and where possible, the relocation of buildings to the landward side of affected properties should be encouraged. The rock walls have an adverse effect on the beach system and are not a good long-term solution to any present or future problems. Significant investment in the upgrading of the rock walls in their present position should be avoided. Instead, funding should be directed towards a planned retreat and the eventual removal of the rock walls.

Alternative management options

The overall objective of a management strategy is to limit the impacts of the rock walls on the beach system and ensure protection of private properties. Establishing a sandy beach seaward of the rock walls will improve the recreational amenity of the area and in enhancing the effectiveness of the rock wall structures. Alternative options that may be considered include:

- complete or partial acquisition of affected properties including site rehabilitation and removal or relocation of rock walls. Costs are likely to exceed $10 million. However, the program could be staged over a number of decades and could include methods of reducing overall costs such as short-term lease-back; or

- the establishment of a control structure in the vicinity of the affected section, along with a limited program of beach nourishment. The structure, possibly in the form of an offshore breakwater, would create a *salient*, modifying the beach's plan shape and hence reducing the anticipated trend of shoreline recession. The high tide range and the potential effects of severe storm events would complicate the design of the structure. A program of beach nourishment would also be required to mitigate the expected erosion effects downdrift. Overall project costs could be as high as $2 million.

Dolphin Heads and Eimeo

The Dolphin Heads and Eimeo area is used extensively for residential purposes, along with some tourist development and areas of open space (figure 60 shows land tenure). A number of freehold properties have been established close to the shoreline.

Erosion prone area widths

A review of erosion prone area widths in the vicinity of Dolphin Heads was undertaken for the Authority in 1987 taking into account the local coastal processes. A further review of this work has been undertaken including the effects of Greenhouse sea-level rise.

The components of the erosion prone area width for Eimeo Beach are shown in table 47. Using these values, the recommended erosion prone area width is 80m, an increase from the existing value of 55m (figures 59 and 60 show the recommended values).

Table 47 Erosion prone area width calculations, Eimeo Beach

Parameter	Value (m)
Long term erosion component (*N* x *R*) (nominal)	10
Short term erosion component (*C*) (estimated)	7
Recession related to the sea-level rise associated with the Greenhouse effect (*G*)	37
Dune scarp component (*D*)	5
Calculated width	80
Existing width	55

Management issues

A series of low rock walls have been constructed to halt erosion along the seaward boundaries of these properties, particularly the beaches on the lee side of Dolphin Heads and Eimeo headland. Several allotments at the end of Eimeo Beach have rock walls on their seaward boundary for protection against damage from storm waves.

Several short rock groynes have been constructed on the rocky intertidal platform in an attempt to encourage the build-up of sandy material near the shoreline at Dolphin Heads. It is unlikely that the groynes will have any long-term effect on improving the beaches and attempts to upgrade the groynes are not recommended.

A number of private properties along the Dolphin Heads to Eimeo section close to the shoreline are vulnerable to storm tide inundation and/or damage from severe wave conditions. The anticipated sea-level rise associated with the greenhouse effect is expected to exacerbate the situation, particularly along the eastern end of Eimeo Beach, where the alignment is controlled by the level of the bedrock platform. A review of the adequacy of the existing protective rock walls along this section should be undertaken to guarantee structural integrity and sufficient crest levels to protect against a storm event with a 100-year return interval.

At the eastern end of Eimeo Beach a number of freehold properties are located within the erosion prone area near the end of the sand spit close to the tidal creek entrance. Due to the close proximity of private dwellings to the shoreline and the resulting vulnerability to erosion and storm tide flooding hazards, it is recommended that:

- increased development density should not be allowed; and
- a program of acquisition of these properties should be undertaken where possible to reduce development rights or convert the private freehold land to an open space designation (this would provide added benefits for public beach access).

Bucasia Beach

Bucasia Beach has formed between the headlands of Eimeo and Shoal Point as a continuous sandy beach. The beach is part of the northerly throughput of sediments derived primarily from the Pioneer River.

Erosion prone area widths

It is recommended that the maximum erosion prone area width of 400m in the vicinity of the entrance to Eimeo creek should be unchanged. A linear transition from zero to 400m is proposed for the erosion prone area width between Eimeo headland and Eimeo Creek.

Analysis of survey data and the assessment of longshore sediment transport fluxes indicate a continuing trend of accretion along Bucasia Beach. The erosion prone area width calculations for the southern section of Bucasia Beach is contained in table 48. Using these values the calculated erosion prone area width is 70m, and the existing value of 80m is considered acceptable.

Table 48 Erosion prone area width calculations, Bucasia Beach (south)

Parameter	Value (m)
Long term erosion component (*N* x *R*) (nominal)	10
Short term erosion component (*C*) (estimated)	10
Recession related to the sea-level rise associated with the Greenhouse effect (*G*)	23
Dune scarp component (*D*)	10
Calculated width	70
Existing width	80

Trapping of sediments on the tidal flats and associated downdrift erosion, similar to that seen at Slade Bay, would occur in Sunset Bay due to sea-level rise. In this case, the affected section of tidal flats is approximately 160,000m^2 in plan area; therefore the downdrift loss is in the order of 1000m^3/a. Over the 3km coastline length of Bucasia Beach, the associated recession would be negligible.

The erosion prone area width for the northern section of Bucasia Beach is shown in table 49. Using these values the recommended erosion prone area width is 70m, reduced from the existing value of 110m. Proposed revisions to erosion prone area widths are summarised in figure 60.

Table 49 Erosion prone area width calculations, Bucasia Beach (north)

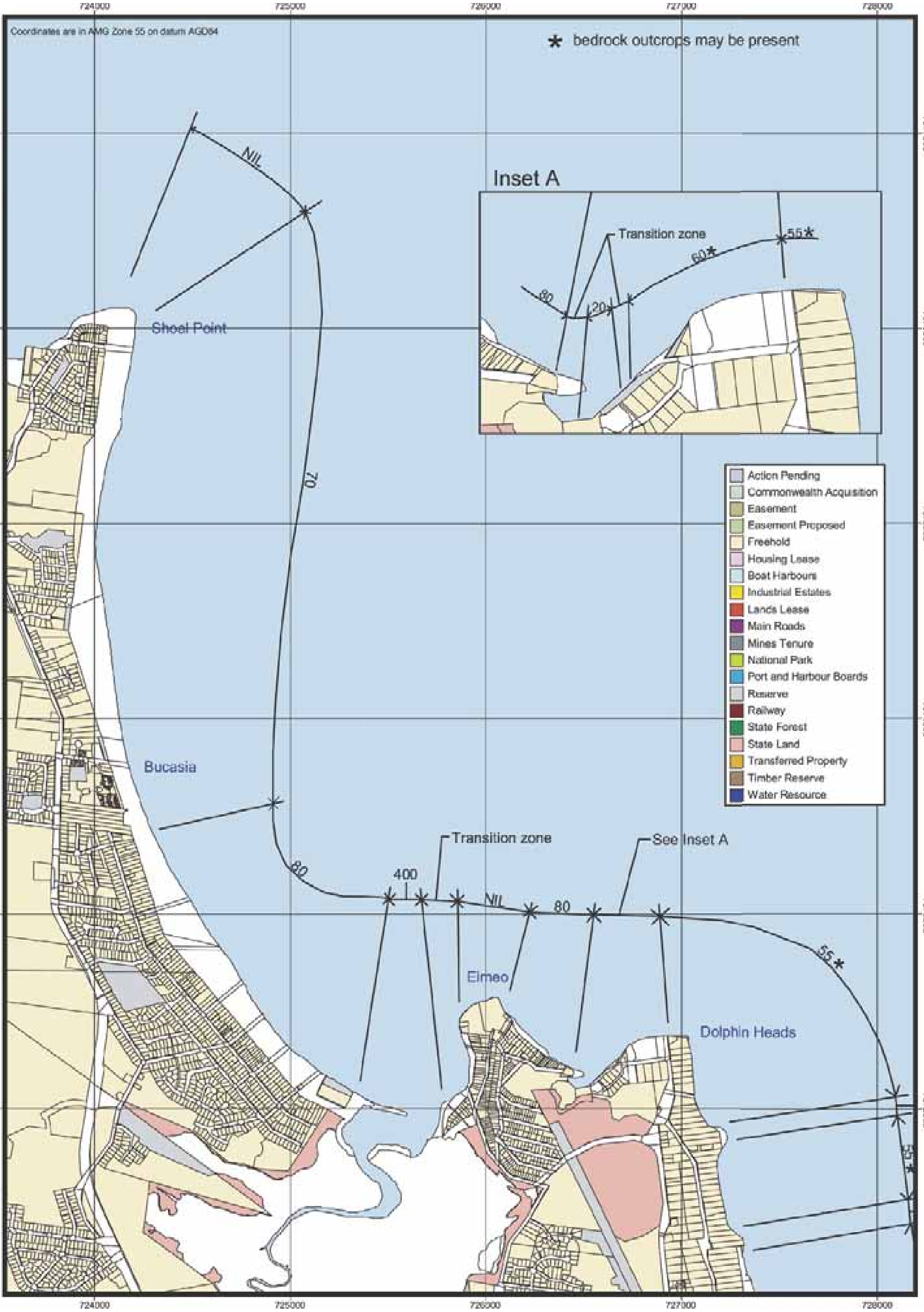
Parameter	Value (m)
Long term erosion component (*N* x *R*) (nominal)	10
Short term erosion component (*C*) (estimated)	15
Recession related to the sea-level rise associated with the Greenhouse effect (*G*)	13
Dune scarp component (*D*)	20
Calculated width	70
Existing width	110

Management issues

Close to the Eimeo Creek entrance, a caravan park has been established near the shoreline. Aside from this, the Bucasia Beach shore front is free from development. Although extensive residential development has extended through to Shoal Point, a wide buffer zone exists between freehold property and the coast (figure 60). This feature, along with the overall trend of accretion, should result in minimal coastal management concerns. It is recommended that the development-free buffer be maintained in its present form.

The caravan park is at risk of inundation from storm tide due to its proximity to the creek entrance. It is recommended that no increase in the density of development be permitted in this area.

Figure 60 Land tenure and revised erosion prone area width, Dolphin Heads to Shoal Point



18 Conclusions and recommendations

Introduction

A detailed review of coastal processes in the Mackay region has been undertaken in order to quantify the behaviour of coastal systems and predict future trends. This review has been used to formulate recommendations for future coastal management. Specific recommendations for individual beaches are detailed in the previous chapter.

Commercial sand extraction

It is likely that applications for sand extraction permits in the coastal areas of the Mackay region will continue in the future. Fill for coastal development, raw materials for the construction industry and possibly sand for beach replenishment are likely to be required on a continuing basis.

The review by GHD (1998) of the commercial opportunities for sand extraction in the Pioneer River system included the following recommendations:

1. Permitted extraction from sites in the lower reaches of the Pioneer River should be reduced from approximately 100,000m^3/a to 22,000m^3/a.
2. The existing extraction from sites between East Point and the southern breakwater of the harbour could continue at a rate of up to 42,000m^3/a.
3. Future alternative extraction operations should consider the reserves of sand and gravel trapped by the water resource structures at Dumbleton, Mirani and Marian.

A further review of the fluvial processes of the Pioneer River has not been undertaken as part of this study. It is apparent from the evidence provided by GHD that the sand and gravel extraction activities are contributing to a net reduction of sediments in the tidal reaches of the river. A reduction of the permitted extraction quantities in the river as proposed by GHD would therefore be prudent.

The analysis of coastal processes undertaken for this study indicates that the net fluvial supply of beach material sized sediments to the coastal system from the Pioneer River is in the order of 85,000m^3/a. Approximately 35,000m^3/a is transported northward along Harbour Beach, where it is trapped by the southern breakwater of the harbour. About 45,000m^3/a accumulates on the Pioneer River entrance bar and a small amount, in the order of 5,000m^3/a, is transported westward from the river entrance towards Town Beach.

Despite the apparent over-extraction of sand from the lower reaches, the fluvial supply from the Pioneer River is expected to continue at the present rate in the medium term. Some reduction may be expected due to the effects of sea-level rise associated with the greenhouse effect.

The commercial extraction of sand from the southern section of Harbour Beach has provided benefits in supplying valuable materials to the local economy. The operations also reduce potential problems associated with windblown sand in the small craft harbour and port area and reduce likely hazards to navigation caused by possible siltation in the harbour entrance.

GHD (1998) considered that the beaches north of the harbour have probably adjusted to the net loss of sand removed by the commercial extraction activities. The present study has shown that this is not the case. The extraction of sand south of the harbour is interrupting the natural coastal processes by removing considerable quantities of sand from the active littoral system and is not sustainable over the long term.

The present study has also shown the vulnerability of many of the Mackay beaches to erosion including the impacts of the anticipated sea-level rise associated with the greenhouse effect. In general, the removal of sand from the tidal flats through commercial extraction activities is not recommended. Site-specific issues are as follows:

- the northern end of Town Beach is accreting at a low rate, partially due to the influence of the Pioneer River entrance training walls, and is not a suitable source for continuing extraction;
- the tidal flats seaward of Town Beach and Far Beach are not suitable as extraction sites as the rates of sediment transport (and therefore infill) are very low. This can be clearly seen in sequences of aerial photographs over previous extraction areas seaward of Town Beach; and
- the estuary of Bakers Creek appears to be a net sediment sink for marine sediments under present and future sea-level conditions. Extraction of sand from within the estuary and the adjacent tidal flats would reduce the quantity of available sediments from the active system and is therefore not sustainable.

The accumulation of sediments near the Pioneer River entrance at an estimated rate of 45,000m^3/a does provide a potential source for commercial sand extraction. The ebb tide delta of the river has been accreting seaward into the lee of Flat Top Island since the changes to the entrance training walls made in the late 19th century. Extraction of the recently deposited material near the edge of the delta would not significantly affect processes on the adjacent coastline.

Based on present trends, it is anticipated that the delta will continue to accrete into the sheltered area in the lee Flat Top Island. Over time, this may have an effect on the hydraulic efficiency of the river entrance and potentially increase the risk of flooding in the city. Maintaining the efficiency of the channel through the bar delta by dredging would therefore avert a worsening of potential flood levels in the Pioneer River.

Commercial extraction of sand from the deeper sections of the Pioneer River entrance delta would probably require the use of specialised plant, such as trailer suction hopper dredges. The establishment and operational costs of this type of plant are clearly higher than the costs of land-based equipment used presently. A cost-effective approach may be to extract sand in large, less-frequent campaigns and stockpile the material at a suitable location onshore. Any proposal for large scale extraction should be subjected to a detailed assessment of potential impacts.

Effects of the harbour walls

The Mackay Outer Harbour was constructed during 1935 to1939. Its design and location are generally regarded as being successful in providing all-tide access to the port for the majority of commercial shipping.

The harbour walls extend some 1,200m offshore from Harbour Beach and have a considerable effect on waves and tidal flows in the adjacent areas. Numerical modelling has shown that tidal current velocities have increased by up to 30 percent at a location immediately seaward of the harbour compared to pre-1935 conditions. The intrusion of the walls into the tidal stream also results in a net residual flow pattern directed towards the harbour. The numerical modelling has shown that the recent extension works for the construction of the small boat harbour appear to have had a negligible additional impact on tidal flows.

The majority of the longshore sediment transport on Harbour Beach is blocked by the southern breakwater. Numerical modelling indicates that negligible longshore sediment transport occurs beyond a point approximately 500m offshore, although a minor quantity of sediment bypasses the harbour naturally by the action of waves and tidal flows. The rate of natural bypassing has not been quantified, but it is likely to be small in comparison with the net longshore sediment transport rate on Harbour Beach. Accretion of southern Harbour Beach has been limited by sand extraction activities. Clearly, a reduction in the rate of extraction permitted in this area will result in a trend of accretion at the southern breakwater and eventually lead to an interruption to navigation of the harbour entrance.

Survey data analysis and numerical modelling have shown that the northern section of Harbour Beach is continuing to respond to the effects of the harbour construction. The section immediately adjacent to the northern breakwater has accreted in response to the reduced wave energy and tidal flows. This accretion, which can be seen in aerial photography, has a small supply both by the natural bypassing of the harbour and artificial placement of sand.

The shoreline at the centre of Harbour Beach north has eroded at a rate of approximately 0.85m/a over the past 20 years in response to the reduced sediment supply. Lamberts Beach and Harbour Beach north have reduced in volume at a combined rate in the order of 13,000m^3/a. This downdrift erosion would have been much higher had it not been offset by the placement of 610,000m^3 of dredged material on the beach to the north of the harbour since 1968.

The interruption of longshore sediment transport along Harbour Beach by the harbour walls is expected to continue, resulting in a noticeable erosion of the northern section of Harbour Beach and Lamberts Beach. In the absence of compensatory placement of sand, coastline modelling indicates that, under present conditions, the centre of Harbour Beach north is expected to recede by approximately 80m over the next 50 years due to the interrupted sediment supply.

The net northward sediment transport bypassing Slade Point has been affected slightly by the altered coastline configuration of Harbour Beach north. The calculation of longshore sediment transport indicates that the rate along Harbour Beach north has reduced from 35,000m^3/a to 33,000m^3/a since harbour construction. In 50 years this is estimated to reduce to 30,000m^3/a in response to the continuing coastal alignment changes.

The presence of the harbour walls and the associated sand extraction south of the harbour are therefore directly resulting in erosion of the beach north of the harbour and will eventually cause erosion problems to beaches further north. Options for future management are described below.

Option: Continued Extraction

Allowing the present extraction arrangements to continue would avert problems in the Port of Mackay but would result in continuing erosion along the beaches to the north. The coastal systems north of Slade Point are vulnerable to loss of sediment supply, although they do not appear to have been significantly affected to date.

Option: Cease or Reduce Rates of Extraction

Conceptually, by limiting or not renewing existing commercial sand extraction permits the net northward littoral transport would eventually be re-established along Harbour Beach. However, the complete establishment of sediment transport past the harbour would take a significant period of time and, due to the changed coastal alignment, the net rate of northward sediment transport at Slade Point would probably remain reduced for several decades.

Allowing the bypassing of the harbour by natural littoral transport would result in a significant maintenance problem for the Mackay Port Authority. A program of regular dredging of the harbour entrance would be required and the control of windblown sand adjacent to the southern wall could become a problem. Due to the serious interruption to the operation of the port, this option is not practical and is unlikely to be considered.

Option: Artificial sand bypassing

The implementation of an artificial sand bypassing system would allow the re-establishment of sediment transport along Harbour Beach and require no increase in maintenance dredging in the harbour.

A range of possible bypassing systems could be considered. The simplest method might be to continue the extraction activities using conventional trucks and earthmoving plant, and deliver the sand to an appropriate site north of the harbour. Selection of an appropriate delivery site would need to take into account a number of environmental impacts including:

- the conservation significance of the Slade Point Reserve;
- the trend of accretion in the area immediately north of the harbour (the outlet site would not be optimally located in this area);
- noise, dust and other impacts of the delivery system;
- interruptions to the recreational value of the beaches; and
- potential windblown sand problems associated with a stockpile at the delivery site.

A preliminary recommendation for a delivery site is Lamberts Beach. Ideally, the sand should be placed near the centre of Harbour Beach north away from the *shadow zone* created by the harbour walls. However, the benefit gained from a delivery site in this location may be negated by the adverse impacts on Slade Point Reserve associated with providing access.

In summary, the most appropriate option to ensure the continuity of sand supply is not adversely affected by the harbour walls is artificial sand bypassing. It is recognised that significant funding and management issues of an artificial sand bypassing system are to be resolved prior to implementation.

Future monitoring

Competent coastal resource planning and management are based on an understanding of prevailing coastal processes. Undertaking of the necessary analyses generally requires many years of wind, wave, current and survey data, and the data need to be reliable and representative. Without them, predictions of shoreline change would be subject to a large degree of uncertainty. For example, the difference between a two-year record and a 20-year wave record may mean an increase in the maximum recorded significant wave height of more than 1m, and a substantial re-evaluation of the magnitude of extreme events.

The cost to the community of inadequate data can be high. Investing in data collection can offset both unnecessary capital expenditure due to over-design and costs associated with an expensive failure resulting from under-design or misunderstanding of natural processes. Investment in data collection reduces uncertainty and continuing expertise is vital to ensure that the data are correctly collected and interpreted (Institution of Engineers, Australia 1993).

The present study has highlighted several limitations in existing local data sets. As a result, the following recommendations are made for the improvement of coastal process data:

- The Mackay coastline is strongly influenced by the Pioneer River. The changes occurring to the tidal delta and the subsequent impacts on surrounding beaches are not easily quantified by the available survey data. It is therefore recommended that a regular program of hydrographic surveys extending over the entrance and ebb tide bar of the Pioneer River be undertaken in conjunction with aerial photography covering the entrance and lower reaches of the River.
- As part of permit requirements, sand and gravel extraction operators are normally required to engage licensed surveyors to perform pre- and post-extraction surveys. These data should be integrated into the long-term survey record for the area.
- In the Town and Far Beach areas, the dune crest provides an important barrier against storm tide inundation. A long-term record of changes to the crest height is not available, but is extremely important for management purposes.
- In general, the beach profile surveys data are limited in the whole region, especially north of Mackay Harbour. It is recommended that a regular survey program be developed to better quantify the coastal changes; these surveys should include land based surveys of the key sections of beach taken during low tides.
- Due to the large tidal range in the study area, nearshore tidal currents have a large impact on sediment transport and, therefore, on shoreline movement. Although extensive current metering and hydrodynamic modelling were undertaken for this study these were on a regional scale and limited nearshore current data are available, especially in the Slade Bay and Dolphin Heads areas. Additional collection of current data will further refine understanding of coastal processes and behaviour where fine scale detail is important.

The development of coastal management plans for Queensland has reinforced the need for a comprehensive long-term data collection program. These plans will be subject to review in the future, necessitating continuing collection of wind, wave, survey and current data to ensure that coastal managers can further refine predictions of shoreline change while allowing for responsible planning.

Degradation of dunes on Harbour Beach (north).

Summary of Recommendations

Commercial sand extraction

The present study has shown the vulnerability of many of the Mackay beaches to erosion and has found that the removal of sand from tidal flats through commercial extraction activities is not recommended, in particular:

- the northern end of Town Beach adjacent to the southern training wall of the Pioneer River is not a suitable source for continuing commercial extraction;
- the tidal flats seaward of Town Beach and Far Beach are not suitable as extraction sites due to the very low rates of infill; and
- extraction of sand from the estuary of Bakers Creek and the adjacent tidal flats is not sustainable.

The continuing accumulation of sediments near the Pioneer River entrance in the sheltered area in the lee of Flat Top Island does provide a potential source for commercial sand extraction. It is recognised however that extraction operations in this area would probably require the use of specialised equipment. In addition, any proposal for large scale extraction should be subjected to a detailed assessment of potential impacts.

Effects of the harbour walls

The interruption of longshore sediment transport along Harbour Beach by the harbour walls is resulting in a noticeable erosion of the northern section of Harbour Beach. The most appropriate option to ensure that the harbour walls do not continue to adversely affect the northward transport of sand is to establish a system of artificial sand bypassing.

Monitoring

A number of improvements to the acquisition of coastal process data may be made:

- a regular program of hydrographic surveys extending over the entrance and ebb tide bar of the Pioneer River be undertaken in conjunction with aerial photography covering the entrance and lower reaches of the River.
- monitoring the crest height of dune systems along Town Beach and Far Beach; and
- greater frequency and spatial resolution of beach profile surveys including a program of upper beach surveys of key sections of the coast.

Rock walls

A number of rock wall structures within the Mackay Coast region may require management action, including:

- Further works to upgrade the rock wall at Illawong Park, Far Beach is not recommended. Ideally, the wall should be removed and existing structures in the park be relocated landward to allow the beach to fluctuate naturally. Alternatively, a program of periodic placement of sand in front of the wall could be established.
- A similar program of beach nourishment of the area seaward of the rock wall at Binnington Esplanade, Town Beach.
- A review of the adequacy of the rock walls along the western coastline of Slade Point, the northern coastline of Blacks Beach and the section from Dolphin Heads to Eimeo should be undertaken. The review should examine both the structural integrity and the potential for overtopping of the walls during a storm event with a 100-year return interval.

Avoiding further development in areas prone to erosion and/or storm tide inundation

A number of coastal areas within the study region have existing development located within the erosion prone area and/or are particularly susceptible to storm tide flooding. These include:

- The Illawong Beach Resort adjacent to the Shellgrit Creek entrance. It is recommended that the density of development should not be increased in this area.
- The foreshore along the northern section of Blacks Beach. In some locations, housing has been constructed seaward of the *natural* coastline. Therefore, where possible, a program of acquisitions or the relocation of buildings to the landward side of affected properties should be encouraged. Further development of high-density land uses such as holiday apartments should be carefully considered.
- At the eastern end of Eimeo Beach a number of freehold properties are located near the end of the sand spit and close to the tidal creek entrance. Where possible a program of acquisition of these properties should be undertaken to convert the private freehold land to an open space designation.
- The caravan park at the southern end of Bucasia Beach. It is recommended that no increase in the density of development be permitted in this area.

Mitigation of storm tide hazard

To protect against storm tide inundation, the dune system along Far Beach and Town Beach should be carefully managed and enhanced where possible.

Vegetation conservation

Most of the native vegetation associations within the study region have been extensively disturbed. Remaining vegetation types could be preserved by incorporating relatively small areas of high habitat diversity in a series of green conservation corridors shaped as a 'T-square' incorporating a coastal strip and a riparian zone.

Coastal zone preservation areas could include Slade Bay, Sandringham Bay and Dalrymple Bay *T-square* green corridors. Of these, the Slade Bay corridor lies within the study area. The Slade Point dune area and Mount Bassett rainforest have high conservation values and have already been set aside for conservation purposes. The incorporation of sites at McCreadys Creek, Andergrove, Slade Bay, Slade Point, Harbour Beach and Mount Bassett into a large group will result in a more resilient and diverse unit for conservation.

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Appendix A Aerial photography

Year	Date		Scale	Flight Area and Run	Film No.
1947	22/08/1947	B/W	30000	Hay Point - Shoal Point Key	MAP3829
1948	06/12/1948	B/W	30000	Blacks Beach - Mackay Harbour Run 3	SVY495
	06/12/1948	B/W	30000	Flat Top Island - Mackay Run 4	SVY495
	06/12/1948	B/W	30000	Round Top Island - Mackay City Run 5	SVY495
	06/12/1948	B/W	30000	Bakers Creek - Dudgeon Point Run 6	SVY495
	06/12/1948	B/W	30000	Shoal Point - Eimeo Run 1	SVY495
	06/12/1948	B/W	30000	Slade Point - Eimeo Run 2	SVY495
	06/12/1948	B/W	30000	Blacks Beach - Mackay Harbour	SVY495
1962	04/08/1962	B/W	12000	Mackay Run 3	Q1270
	31/08/1962	B/W	12000	Mackay Run 2	Q1292
	31/08/1962	B/W	12000	Mackay Run 3	Q1292
1970	09/04/1970	B/W	4800	Mackay Harbour Run 1	Q2194
	09/04/1970	B/W	4800	Harbour Beach Run 2	Q2194
	09/04/1970	B/W	4800	Mackay Harbour Run 4	Q2194
	09/04/1970	B/W	4800	Mackay Airport Run 10	Q2194
	09/04/1970	B/W	12000	Shoal Point Run 1	Q2194
	09/04/1970	B/W	12000	Bucasia Run 2	Q2194
	16/05/1970	B/W	12000	Blacks Beach Run 4	Q2198
	16/05/1970	B/W	12000	Blacks Beach - Slade Point Run 5	Q2198
	16/05/1970	B/W	12000	McCreadys Creek Run 6	Q2198
	16/05/1970	B/W	12000	Mackay Harbour Run 7	Q2198
	16/05/1970	B/W	12000	Mackay Harbour Run 8	Q2198
	16/05/1970	B/W	12000	Mackay City Run 9	Q2198
	16/05/1970	B/W	12000	Mackay Airport Run 10	Q2198
	16/05/1970	B/W	12000	Mackay Airport Run 11	Q2198
	16/05/1970	B/W	12000	Mackay Airport Run 12	Q2198
	16/05/1970	B/W	12000	Backers Airport Run 13	Q2198
	12/06/1970	B/W	3000	Slade Point	AAM5109
1972	20/04/1972	B/W	8000	Pioneer River - Bakers Creek	AAM7005

.1974	27/05/1974	C	12000	Bell Creek - Slade Point Run 17	Q2853
	27/05/1974	C	12000	Mackay Harbour - Neils Beach Run 18	Q2854
	27/05/1974	C	12000	Shoal Point - Green Island Run 19	Q2854
	27/05/1974	C	12000	Bucasia - Williamsons Beach Run 20	Q2854
	10/06/1974	C	12000	Alligator Creek - Slade Point Run 16	Q2874
	07/09/1974	C	12000	Bell Creek - Slade Point Run 17	Q2880
1977	09/08/1977	C	12000	Bucasia - Williamsons Beach Run 20	Q3432
	12/08/1977	C	12000	Alligator Creek - Slade Point Run 16	Q3433
	12/08/1977	C	12000	Mackay Harbour - Neils Beach Run 18	Q3433
	12/08/1977	C	12000	Shoal Point - Green Island Run 19	Q3433
1978	28/11/1978	C	12000	Bucasia - Williamsons Beach Run 20	Q3438
	29/11/1978	C	12000	Mackay Harbour - Neils Beach Run 18	Q3438
	29/11/1978	C	12000	Shoal Point - Green Island Run 19	Q3438
1979	02/08/1979	C	12000	Mackay Harbour - Neils Beach Run 18	Q3695
	02/08/1979	C	12000	Shoal Point - Green Island Run 19	Q3695
	02/08/1979	C	12000	Bucasia - Williamsons Beach Run 20	Q3695
1981	07/07/1981	C	12000	Alligator Creek - Slade Point Run 16	QP3882
	07/07/1981	C	12000	Bell Creek - Slade Point Run 16	QP3882
	07/07/1981	C	12000	Mackay Harbour - Neils Beach Run 18	QP3882
	07/07/1981	C	12000	Shoal Point - Green Island Run 19	QP3882
	07/07/1981	C	12000	Bucasia - Williamsons Beach Run 20	QP3882
1982	29/03/1982	C	12000	Bell Creek - Slade Point Run 17	QP3871
	29/03/1982	C	12000	Bucasia - Williamsons Beach Run 20	QP3871
	28/04/1982	C	12000	Alligator Creek - Slade Point Run 16	QP4035C
	28/04/1982	C	12000	Mackay City - Slade Point Run 17A	QP4035C
	05/05/1982	C	12000	Shoal Point - Green Island Run 19	QP4032C
	13/06/1982	C	12000	Mackay Harbour - Neils Beach Run 18	QP4041C
1985	23/06/1985	C	12000	Shoal Point - Green Island Run 19	QP4468
	25/06/1985	C	12000	Alligator Creek - Slade Point Run 16	QP4460
	25/06/1985	C	12000	Bell Creek - Slade Point Run 17	QP4460
	25/06/1985	C	12000	Mackay Harbour - Neils Beach Run 18	QP4460
	25/06/1985	C	12000	Bucasia - Williamsons Beach Run 20	QP4460
	14/07/1985	C	50000	Alligator Creek - Green Island Run 5	QP4496
1990	09/06/1990	C	50000	Kelvin - Slade Pt Run 4	Q4901
	09/06/1990	C	50000	Mount Canven - Shoal Point Run 5	Q4901
	09/06/1990	C	50000	Slade Point - Mount Jumper Run 6	Q4901

1991	26/06/1991	C	12000	Alligator Creek - Slade Point Run 16	Q4894
	26/06/1991	C	12000	Alligator Creek - Slade Bay Run 17	Q4894
	26/06/1991	C	12000	East Point - Pioneer River Run 17A	Q4894
	26/06/1991	C	12000	Sandringham Bay - Bakers Creek Run 17B	Q4894
	26/06/1991	C	12000	Slade Island - Green Island Run 18	Q4894
	26/07/1991	C	12000	Bucasia - Green Island Run 19	Q4897
	26/07/1991	C	12000	Bucasia - Sand Bay Run 20	Q4896
1993	19/06/1993	C	12000	Alligator Creek - Slade Point Run 16	Q5070
	19/06/1993	C	12000	Alligator Creek - Slade Bay Run 17	Q5070
	19/06/1993	C	12000	East Point - Pioneer River Run 17A	Q5070
	19/06/1993	C	12000	Sandringham Bay - Bakers Creek Run 17B	Q5070
	20/06/1993	C	12000	Slade Island - Green Island Run 18	Q5070
	20/06/1993	C	12000	Bucasia - Green Island Run 19	Q4651
	20/06/1993	C	12000	Bucasia - Sand Bay Run 20N	Q5070
	25/06/1993	C	12000	Alligator Creek - Slade Bay Run 1	QPC4947
	25/06/1993	C	12000	Mackay - Shoal Point Run 2	QPC4947
	25/06/1993	C	12000	Slade Island - Shoal Point Run 3	QPC4947
	25/06/1993	C	12000	Bakers Creek - Mackay Run 4	QPC4947
	17/08/1993	C	12000	Kelvin - Slade Point Run 4	Q5149
	17/08/1993	C	50000	Mount Canven - Shoal Point Run 5	Q5149
	17/08/1993	C	50000	Slade Point - Mount Jumper Run 6	Q5149
	15/12/1993	C	12000	Kelvin - Slade Point Run 4S	Q5241
1996	18/04/1996	C	12000	Pioneer River Run 17A	QPC5209
1997	29/10/1997	C	12000	Alligator Creek - Slade Bay Run 16	QAP5419
	01/11/1997	C	12000	Alligator Creek - Slade Point Run 17	QAP5420
	01/11/1997	C	12000	Slade Island - Green Island Run 18	QAP5420
	01/11/1997	C	12000	Bucasia - Green Island Run 19	QAP5420
	01/11/1997	C	12000	Bucasia - Green Island Run 20	QAP5420