Lord Howe Island
Coastline Hazard Definition and Coastal Management Study

Prepared for the Lord Howe Island Board by Haskoning Australia Pty Ltd

9 September 2014

Issue 5 (Final)

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EXECUTIVE SUMMARY

Haskoning Australia Pty Ltd was engaged by the Lord Howe Island Board to complete a Coastal Hazard Definition and Coastal Management Study for Lord Howe Island, as set out herein. There are a number of coastline management issues at Lord Howe Island, in particular erosion/recession threatening Lagoon Road (and underground cables) at Lagoon Beach near Windy Point.

Erosion of the Windy Point area has been documented for some time. The road at Windy Point was undermined and rebuilt about six times prior to 1965, and also in 1985. Protective works (such as 44 gallon drums and gabions) were placed at Windy Point in the late 1980's in an attempt to limit this erosion. Ongoing coastal storms over the next few years, and the continuing risk of damage to Lagoon Road, led to the construction of a Seabee revetment at Windy Point in 1999.

An airport was opened at Lord Howe Island in 1974, which included a 70m protrusion of the runway into the Lagoon, protected by a rock revetment. Although some consider that this runway protrusion interrupted longshore sediment transport and caused erosion/recession at Windy Point, it is evident that the area was experiencing erosion prior to the runway construction. After construction of the Seabee revetment in 1999, erosion began to be experienced to its north, ultimately leading to construction of a sand-filled geotextile container (bag) wall in the eroding area in 2011. However, erosion has continued to the north of the bag wall since that time.

The most southerly coral reef in the world is located at Lord Howe Island, with an average crest level of 1.0m AHD, which is 0.2m below mean sea level in the Lagoon (unlike the Australian mainland, AHD at Lord Howe Island is not equivalent to mean sea level, but is at a level of extreme low tide known as Chart Datum). However, the elevation of reef crests is variable, and wave energy is likely to be focussed on the Windy Point area due to lower reef crests directly offshore from Windy Point.

The Lagoon adjacent to the reef has an average depth of about 2m, but with a much deeper area near Comets Hole, which is likely to act as a sink for sediment moving between the reef crest and shoreline. It has been estimated that sediment began to accumulate over basalt bedrock in the Lagoon about 4,600 years ago, with greater sediment availability after 2,900 years ago as sediment filled sinks in the Lagoon floor and reached a shallow enough depth to be reworked by waves. Increasing westerly wind strength from about 700 years ago, combined with falling sea levels and this lagoon infilling, facilitated increased sediment movement from the reef crest and the Lagoon bed to the western shore of Lord Howe Island. This caused rapid development of beaches about 600 years ago. Sediment may still be moving landward across the Lagoon bed and adding to subaerial beach sediments.

Rates of change of sand volume per year in various compartments along Lagoon Beach and Cobbys Beach, based on review of 5 dates of aerial photography and photogrammetric data from 1965 to 2011 and measured above 0m AHD, are depicted in Figure ES1. It is evident that most of the length of beaches along the Lagoon at Lord Howe Island have been growing in sand volume or moving seaward (prograding). The only two areas reducing in volume or moving landward (receding) are located immediately north and south of the runway revetment, Seabee revetment, and bag wall structures.

Further investigation of the sources and transport direction of sediment in the wider Lagoon would be warranted to inform a longer term understanding of coastal processes and to inform the design of any future beach nourishment campaigns or other works. A preliminary conceptual model of sediment transport processes that is an attempt to document the observed beach changes and is consistent with observed circulation patterns is depicted in Figure ES2.

Figure ES1: Summary of long term (1965 to 2011) sand volume changes at Lagoon Beach and Cobbys Beach

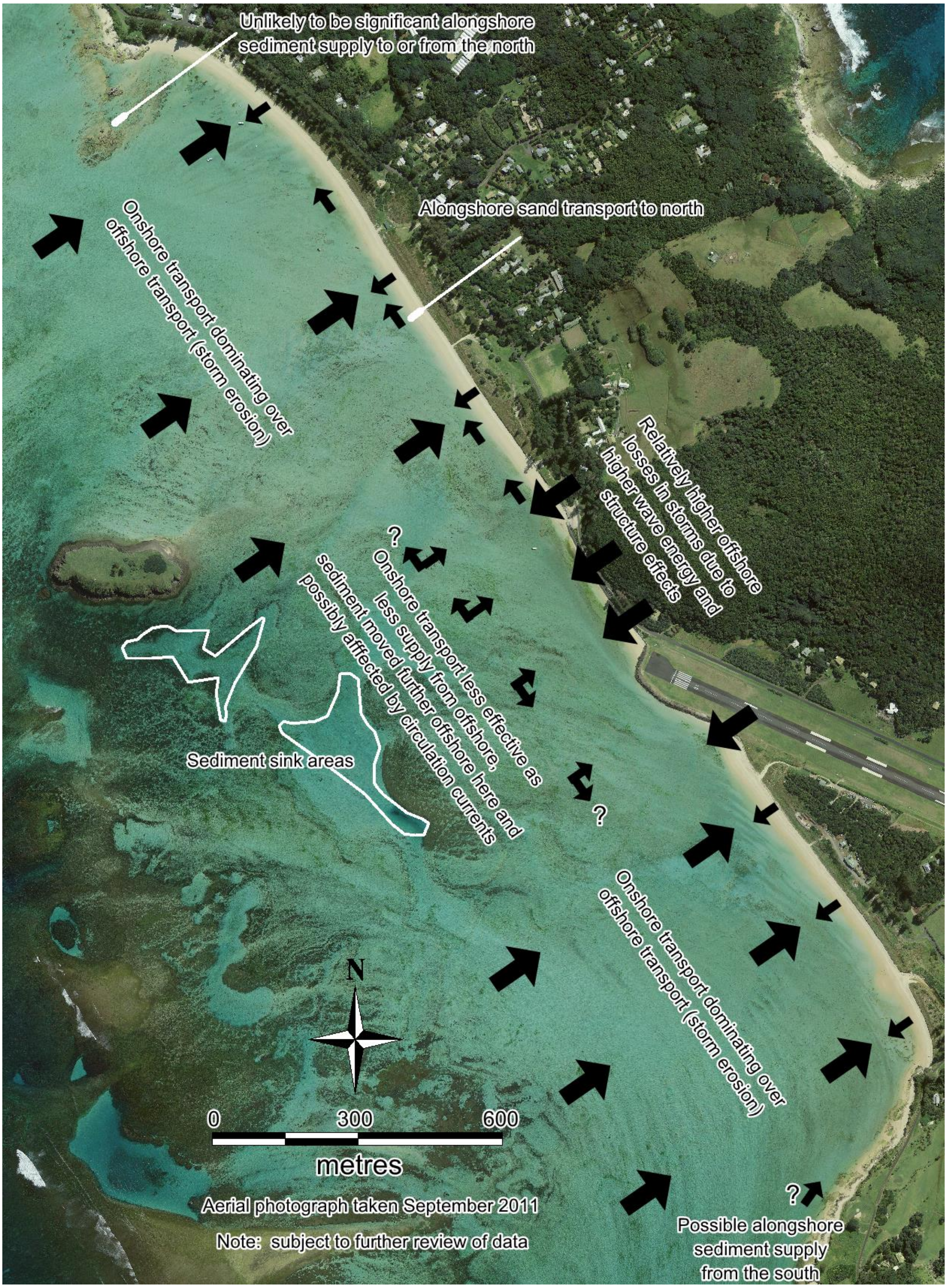


Figure ES2: Preliminary conceptual model of sediment transport processes in Lagoon and at Lagoon Beach and Cobbys Beach

Immediate (as of 2011), 2050 and 2100 Coastline Hazard Lines (defined at the landward edge of the Zone of Slope Adjustment) are delineated herein. The key assets at immediate risk of damage at Lagoon Beach and Cobbys Beach are Pinetrees boatshed and Lagoon Road near the bag wall. Considering 2050 and 2100 timeframes, the boatsheds at the northern end of Lagoon Beach begin to become at risk, as does the Aquatic Club. Without the protection of the Seabee revetment and rock revetment, Lagoon Road and the runway would be at immediate risk of damage, indicating the importance of maintaining these structures.

Immediate management actions to reduce the risk of undermining at Lagoon Road (for which investigations should be commenced or actions undertaken now) are as follows:

- discontinue beach scraping;
- develop Emergency Action Plan;
- alongshore sand relocation;
- beach nourishment;
- beach profile surveys; and
- a sand tracing study.

A number of potential future long term action options for managing the risk of undermining of Lagoon Road are also assessed, including moving Lagoon Road and nearby underground cables landward; and construction of a seawall/revetment.

Entrance management of Old Settlement Creek, Cobbys Creek and Soldiers Creek is also considered, particularly in terms of managing Sallywood Swamp Forest (a Critically Endangered Ecological Community) and flooding. Where possible, it is recommended that a natural entrance opening regime is maintained. The key effect of entrance openings in terms of reducing the health of the Sallywood Swamp Forest is the ingress of saline water. Saline intrusion could be reduced by:

- mechanically closing off an entrance immediately after a breakout event; and/or
- maintaining the beach berm level seaward of a creek at a higher level; and/or
- mechanically opening an entrance (if that was required) on a low to rising tide.

All of the above actions would be counterproductive to any requirements to manage an entrance to reduce inundation (flooding) levels to protect infrastructure.

There is a substantial delta of sand formed within the Lagoon seaward of Old Settlement Creek. There may be consideration of using this delta as a source of sand for beach nourishment, subject to detailed assessment. A smaller delta is also present at Cobbys Creek.

Other relevant management actions are developed, namely:

- maintain reef health;
- monitor Sallywood Swamp Forests;
- maintain dune vegetation; and
- install signage at the base of cliff areas.

CONTENTS

1. INTRODUCTION

1.1 Study Brief and Report Objectives

The Lord Howe Island Board (Board) released a "Technical Brief for the Preparation of a Coastal Hazard Definition and Coastal Management Study for Lord Howe Island" to selected consultants in May 2012. After submitting a tender, Haskoning Australia Pty Ltd (a company of Royal HaskoningDHV) was engaged to complete the investigation in June 2012.

In the Brief, the following key coastline management issues at Lord Howe Island were listed by the Board:

- Beach erosion / shoreline recession: previous studies identify that following construction of the Aerodrome, longshore drift has become a significant problem. Works have recently been completed to stabilise the sand dune at northern end of the Windy Point Seabee revetment wall. The Island has experienced significant erosion to the north of this wall, with potential to impact on the main north to south road, high voltage power line and the Pinetrees boatshed. Erosion is also affecting infrastructure at Neds Beach and Little Island.
- Coastal lagoon / watercourse entrance instability: Intermittently Closed and Open Lakes and Lagoons (ICOLLs) at Old Settlement Creek, Cobbys Creek, and Soldiers Creek are currently opened on an ad hoc basis. Appropriate triggers need to be determined for when ICOLLs should be opened to protect infrastructure and environmental values.
- Coastal cliff and slope instability, particularly at Neds Beach, Middle Beach and Signal Point.
- Threats from climate change, particularly increased storm intensity and frequency and sea level rise, on aquatic and fringing ecological communities and foreshore development.
- A resource assessment of sediment budgets around Lord Howe Island has not been conducted meaning there is a lack of guidance for the sustainable use of sand / rock for construction purposes.
- Beach scraping has been conducted on an as needs basis and potential best practice beach scraping and renourishment activities for Lord Howe Island are unknown.
- A clear understanding of coastal processes does not inform development proposals such as a proposed slipway and boat sheds. An understanding of these coastal processes would assist in the assessment of development proposals.

The key coastline management issue at Lord Howe Island is erosion/recession threatening Lagoon Road (and an underground high voltage cable and telecommunications cable) at Lagoon Beach, immediately north of a Seabee revetment and sand-filled geotextile wall constructed in 1999 and 2011 respectively. In the report herein, coastal processes and coastline hazards are described in the key area of interest (incorporating this eroding area), namely Lagoon Beach and Cobbys Beach within the Lagoon on the western side of Lord Howe Island. Recommended immediate management options, and potential future management options, to address this key management issue are also presented.

Coastline hazard lines are delineated at Lagoon Beach and Cobbys Beach for immediate, 2050 and 2100 planning periods, including consideration of climate change. There is also discussion on watercourse entrance management and cliff stability, and guidance on appropriate beach scraping and use of sand for beach nourishment.

It is recognised that there are also coastline hazards at other beaches in the study area, for example infrastructure at potential risk of damage at Neds Beach. However, without photogrammetric data being available for this beach, coastline hazards were not able to be determined.

1.2 Vertical Datum

Lord Howe Island Tidal Datum (LHITD) is the datum used for water level measurements that are currently undertaken by Manly Hydraulics Laboratory (MHL) at the jetty north of Signal Point in the Lagoon at Lord Howe Island.

In the NSW Department of Lands "Survey Control Information Management System", the levels of permanent marks and the like at Lord Howe Island are referenced to a vertical datum of AHD71[1]. For example, PM 1084 is at a level of 7.678m AHD.

A hydrographic datum was established at Lord Howe Island in 1954. Based on advice from Zarina Jayaswal (Deputy Director of Tides and Geodetic Control, Australian Hydrographic Office):

- what is referred to as Australian Height Datum (AHD71 or AHD) at Lord Howe Island is in fact the 1954 hydrographic datum;
- Australian Height Datum on Lord Howe Island has no relationship to AHD71 as defined in Footnote 1, that is no relationship to mean sea level on the Australian mainland;
- the 1954 hydrographic datum is also known as NVM/C/447, LHI-16 and PM 1030;
- the 1954 hydrographic datum was adopted as the land surveying datum at Lord Howe Island (and subsequently misnamed as AHD);
- CSIRO set up water level measurements at Lord Howe Island from 1953 to sometime after 1963, and their tide gauge zero was approximately the same as the 1954 datum (0.004m below); and
- the current MHL tide gauge zero is 0.144m above the 1954 datum (that is, 0.144mm above AHD).

Based on data collected by MHL from 1995 to 2010, mean sea level at the jetty at Lord Howe Island is 1.089m LHITD, that is 1.233m relative to 1954 datum and AHD (obtained by adding 0.144m). CSIRO determined mean sea level at the jetty as being 1.12m AHD based on 1 year of data from 1953 to 1954.

Therefore, unlike the Australian mainland where Australian Height Datum (0m AHD) is approximately equal to mean sea level at present, at Lord Howe Island the mean water level in the Lagoon is about 1.2m AHD. The AHD datum at Lord Howe Island is actually equivalent to a 1954 hydrographic (chart) datum that was misnamed as AHD in the past.

For consistency, unless stated otherwise, all levels herein are referred to AHD. The reason AHD was selected is that this is the datum adopted for land levels on Lord Howe Island by the Department of Lands, so is used by surveyors on the Island as the standard vertical datum. However, as noted above, it should be recognised that AHD at Lord Howe Island is not the same as mean sea level in the Lagoon, and has been incorrectly denoted as being the same as AHD71.

Any levels referred to Chart Datum (1954 hydrographic datum) are equivalent to AHD. As noted above, to convert from LHITD to AHD, add 0.144m.

[1] In May 1971, Geoscience Australia, on behalf of the National Mapping Council of Australia, assigned the 1966 to 1968 mean sea level at 30 tide gauges around the Australian mainland coast as a value of 0.000m on Australian Height Datum (AHD). The resulting datum surface, with some minor modifications, has been termed AHD71 since then (Geoscience Australia, 2014).

1.3 Costings

Provision of cost estimates for potential options (such as protective works) to manage coastline hazards was not included in the scope of work for the investigation reported herein. That stated, to assist the client, order of magnitude costs for some options have been estimated herein.

The construction cost estimates were based on the experience of Haskoning Australia on the NSW mainland coast, using judgement as a firm of practising professional engineers familiar with the construction industry. The estimates are only approximate as none of the potential options have even conceptual designs, and costs would be dependent on design factors such as rock or bag size, toe level, crest level, and number of layers. The construction cost estimates cannot be guaranteed as the firm has no control over Contractor's prices, market forces, nor competitive bids from tenderers. The construction cost estimates may exclude items which should be considered in a cost plan. Examples of such items are design fees, project management fees, authority approval fees, contractors risk and project contingencies (eg to account for construction and site conditions, weather conditions, ground conditions and unknown services). The construction cost estimates are not to be relied upon in any way. If reliable cost estimates are required, further investigations would need to be undertaken.

Furthermore, actual costs could reduce depending on the amount of labour and equipment that could be provided by Board staff. Unless stated otherwise, costs have been estimated assuming that all work would be undertaken by an external contractor.

1.4 Structure of Report

The report herein is set out as follows:

- the geographical setting of Lord Howe Island is discussed in Section 2, with additional site photographs and observations in **Appendix A**;
- the historical setting of Lord Howe Island is outlined in Section 3, including a general history since discovery in 1788, and a history of coastline management (including information on protective works undertaken near the southern end of Lagoon Beach since 1974);
- features of the study area are described in Section 4, including geology, the coral reef and Lagoon, World Heritage listing, and land use;
- the planning framework at Lord Howe Island is described in Section 5;
- a review of data collected as part of the investigation reported herein is provided in Section 6, including aerial photography and photogrammetric data (with analysis in **Appendix B**), sediment samples (with analysis in **Appendix C**), bathymetric data, water levels, wave data and meteorological data;
- coastal processes are outlined in Section 7;
- erosion/recession coastline hazards are described in Section 8;
- cliff stability is considered in Section 9;
- coastal inundation is discussed in Section 10;
- watercourse entrance management is described in Section 11;
- immediate management actions and potential future management action options are listed in Section 12 and Section 13 respectively;
- approvals required for potential works are discussed in Section 14; and
- conclusions and references are given in Section 15 and Section 16 respectively.

2. GEOGRAPHICAL SETTING

Lord Howe Island is located about 760km north-east of Sydney (at latitude 31.5°S and longitude 159.1°E) within the Pacific Ocean (Figure), and is thus exposed to waves from all directions. An aerial photograph of the Island is depicted in Figure 2. Key features include:

- The Lagoon (a lagoon enclosed by a coral reef on the western side of the Island, the most southerly coral reef in the world and the only coral reef in NSW territorial waters);
- mountainous terrain over the southern two-thirds of the Island (within a Reserve that is known as the Lord Howe Island Permanent Park Preserve); and
- the main settlement area to the north of the Airport.

Lord Howe Island extends about 11km from north to south and is about 3km wide at its widest point. The Lagoon is about 1.2km wide between the reef and shoreline, and is relatively shallow (average depth of about 2m).

An aerial photograph of the entire Lagoon area is provided in Figure 3. Lagoon Beach has been defined herein to extend from Signal Point in the north to the runway (where it juts out into the Lagoon) in the south, over a length of about 1.7km. Cobbys Beach has been defined to extend from the runway in the north to Cobbys Corner in the south[2], over a length of about 0.8km.

A closer view of the Lagoon Beach and Cobbys Beach area is provided in Figure 4. The main reef passages, which are much deeper than the surrounding Lagoon (with depths up to about 11m in North Passage, 19m in Erscotts Passage and 17m in South Passage), are also identified in Figure 4.

The study area for the investigation reported herein essentially comprised:

- the beaches adjacent to the Lagoon on the western side of the Island (Lagoon Beach and Cobbys Beach);
- Neds Beach, Middle Beach and Blinky Beach on the eastern side of the Island; and
- the entrances to Old Settlement Creek, Cobbys Creek[3] and Soldiers Creek on the western side of the island (where these creeks discharge on to beaches).

Given the location of key coastline management issues at Lord Howe Island being at Lagoon Beach, most of the focus of the investigation reported herein was on this area.

A selection of photographs of Lord Howe Island is provided in **Appendix A**.

[2] Note that "Cobbys Beach" is not an official name recognised by the Geographical Names Board of NSW, but has been denoted herein to clearly identify the beach extending south of the runway. In other reports Cobbys Beach has been denoted as "South Lagoon Beach" or "Lagoon Beach", which can cause confusion with the beach located north of the runway.

[3] Also known as Golf Course Creek.

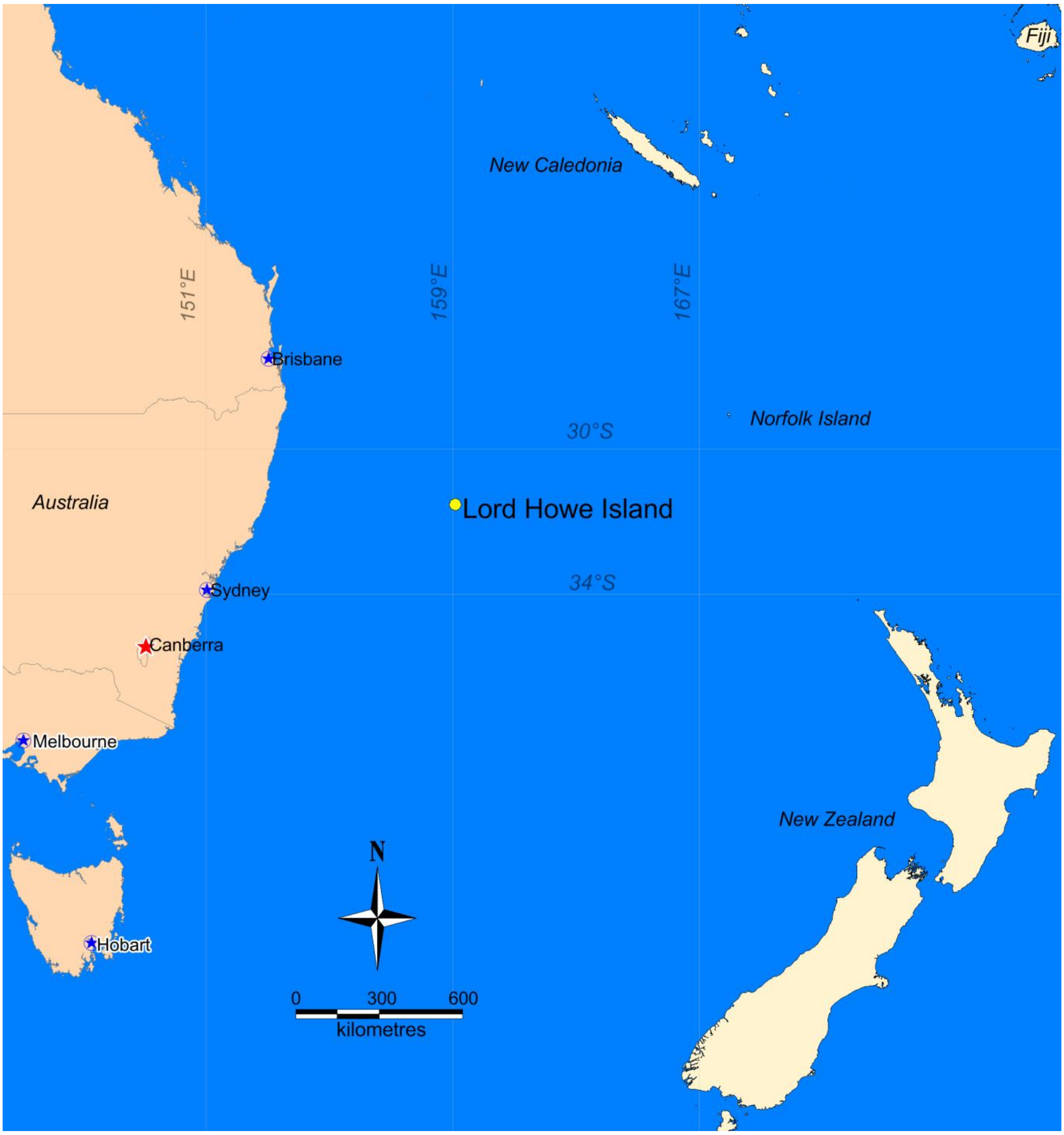


Figure 1: Location of Lord Howe Island in Pacific Ocean

Figure 2: Aerial photograph of Lord Howe Island with key features identified

Figure 3: Aerial photograph of Lagoon area at Lord Howe Island

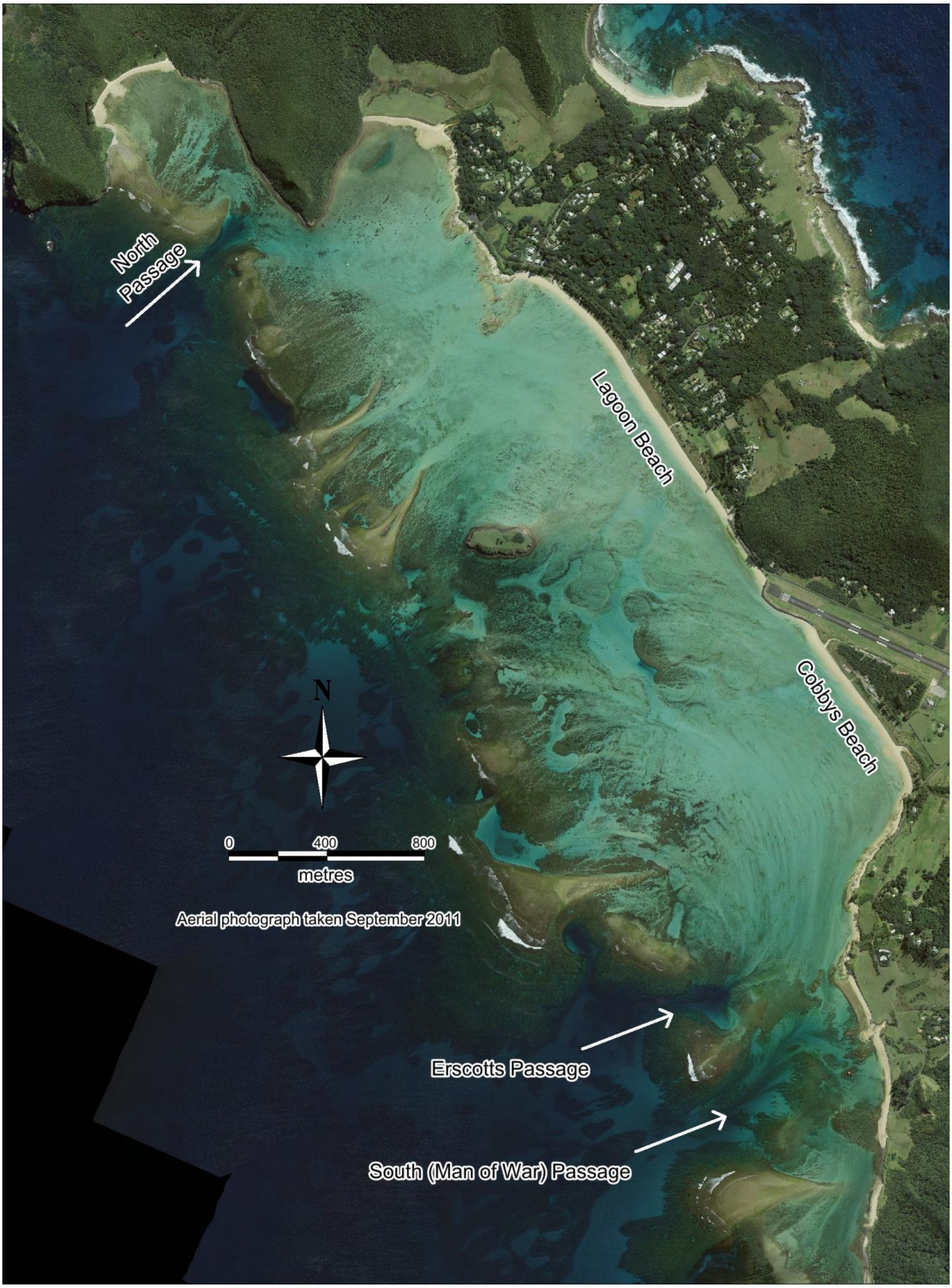


Figure 4: Aerial photograph of Lagoon Beach and Cobbys Beach area at Lord Howe Island

Short (2007) identified 15 sandy beaches at Lord Howe Island, namely:

- 4 beaches along the 19km long eastern shore (Neds Beach, Middle Beach, Blinky Beach and Boat Harbour Beach, moving north to south);
- 1 beach along the 3km long northern shore (Old Gulch); and
- 10 beaches along the 14km long western shore (North Beach, Pebbly Beach, Old Settlement Beach, Jetty Beach, Lagoon Beach, Cobbys Beach[4], Lovers Bay, Johnsons Beach, Kings Beach and Salmon Beach, moving north to south).

[4] Termed South Lagoon Beach by Short (2007).

3. HISTORICAL SETTING

3.1 General History

Information outlined in this Section was derived from Rabone (1972) unless stated otherwise.

The first recorded sighting of Lord Howe Island was on 17 February 1788, when Lieutenant Henry Lidgbird Ball, commander of the ship *Supply*, identified and named it on route to Norfolk Island from Sydney. On the return journey, a party landed on the island on 13 March 1788, the first known human's to set foot there.

Nichols (2006) noted that Ball was accompanied on the journey to Norfolk Island by Captain Hunter and Major Ross on the ship *Sirius*. On 9 March 1788, Hunter described the Lagoon area of Lord Howe Island as follows: "on the west side there is a bay, off which lies a reef parallel to the shore, with good swatches, or passages through for boats; this reef breaks off the sea from the shore, which is a fine sandy beach, so there is no difficulty in landing".

Ball visited Lord Howe Island again in May 1788, with the aim of procuring turtles (which were abundant in the first visit), which was unsuccessful (presumably due to the turtles migrating north away from the island). Ball returned to Sydney, but three other ships of the First Fleet stopped at Lord Howe Island in May 1788 on route to England via China. This included Captain Gilbert of the *Charlotte*, who noted that "the passage between the reefs which shelter the beach, I found to be somewhat intricate".

Other visits from the *Supply* occurred in November 1789 and January 1790, but after this there is no record of visits for a number of years.

The whaling industry commenced in the area (known as the Middle Whaling Ground) in the early 1800's, with Lord Howe Island frequently visited by whaling vessels. Continuous settlement on the island commenced in 1834, when the whaling ship *Caroline* arrived with John Blinkensorp as master. They landed at Blinky Beach (previously known as Blinkenthorpe Beach, a misspelling of Blinkensorp) and lived adjacent to Old Settlement Beach where there was a constant stream of fresh water. Blinkensorp brought 8 settlers to the island, 3 men from New Zealand with their Maori wives and 2 Maori boys.

In about December 1834, HJ White of the Surveyor-General's Department was sent to Lord Howe Island to obtain a survey and report on the suitability of the island for a penal settlement. This penal settlement never eventuated. As noted by Nicholls (1951), White described several reef passages as only having about "five or six feet of water at low tide", which would suggest that the passages had average depths of about 2m, far shallower than the current depths in North, Erscotts and South passages (which exceed 10m, see Section 2)[5]. White also noted that the average depth in the

[5] Nicholls (1951) also noted this anomaly, but did not give an explanation of the reasons for the change except that he considered that depression of coral rock had occurred in the passages. As noted herein (overleaf), North Passage was deepened by blasting in 1880, but it is uncertain how the other passages were deepened (assuming that they were). Clive Wilson (long-term resident at Lord Howe Island, personal communication) was not aware of changes in the reef passages since the 1950's, except for some coral growth in the vicinity of North Passage and North Bay, and east of Erscotts Passage Further investigations of the stability of the passages, reasons for changes (if any) and implications of any changes on hydrodynamics and sediment transport may be relevant. That stated, it is possible that White was referring to depths on the inner (eastern/landward) side of the passages within the Lagoon (which are about 2m on average), and that no significant changes to depths in the passages have occurred.

Lagoon was about "1 fathom", that is about 1.8m, which is similar to the present average Lagoon depth.

In subsequent years, whalers regularly visited the island for water, fuel and refreshment (in the order of 70 to 80 vessels per year)[6], and the 8 original settlers remained until 1841 when they were bought out by Captain Owen Poole and Richard Dawson. A Dr Foulis and his family joined them in 1844. By 1851, 16 people were living at Lord Howe Island.

Between 1851 and 1854, Captain Henry M Denham regularly visited in *HMS Herald*, carrying out the first complete hydrographic survey of the island. By 1876, visiting ships were less regular, with 6 to 12 months sometimes passing without a visit. The Kentia Palm industry commenced in 1878.

On 29 October 1880, Surveyor Berry arrived with assistant Gibbons to carry out a complete survey of Lord Howe Island. Rocks obstructing the northern entrance through the reef to the Lagoon were blown up by dynamite on 5 and 6 December 1880. The last known whaling ship to visit the island came in 1881.

The first photographs of Lord Howe Island were taken in 1882 (Nichols, 2006). By this time, Lord Howe Island had become a stable community (Lord Howe Island Museum, 2014). A Lord Howe Island Board of Control was appointed in 1913. Primarily because of issues relating to land tenure, the *Lord Howe Island Act 1953* was established (Nichols, 2006).

The Navy made an attempt to deepen North Passage in the 1950s, but the blasting was not successful and there was little change in depth (Clive Wilson, long-term resident at Lord Howe Island, personal communication).

Rainfall readings commenced at Lord Howe Island in 1886, with other climate data recorded from 1887, continuing until 1939. The Bureau of Meteorology established a station at the main settlement (current post office) in 1939, then moved to above Middle Beach in 1955, and to the Airport in 1988 (Nichols, 2006). Further information is provided in Section 6.6.

Tourists first came to the island in around 1900 by ship, and tourist visitation boomed post World War II with the arrival of flying boats (seaplanes), which operated out of Rose Bay in Sydney. An airstrip was opened in 1974, enabling twin-engine planes to begin flying to the island (Lord Howe Island Tourism Association, 2014).

3.2 Coastline Management History (Including Works Near Southern End of Lagoon Beach)

The area near Windy Point had a history of erosion threatening to undermine Lagoon Road, up until a Seabee revetment was constructed at the location in 1999. Erosion of this area was occurring prior to the construction of the runway revetment in 1974, based on discussions with long term residents of Lord Howe Island. Manidis Roberts Consultants (1993) also stated that the road at Windy Point had been undermined and rebuilt about six times in the past (up until 1965), prior to the runway construction. They considered that between 1918 and 1984 there was an average of nearly two

[6] Nichols (2006) noted that sand was also sought by visiting whalers (and scattered on ship decks to reduce the risk of slipping).

cyclones per year which caused severe storms on the western (Lagoon) side of Lord Howe Island, with 10 cyclones in 1963, six in 1967, five in 1956 and five in 1957[7].

In September 1985, storm waves cut a back beach erosion escarpment about 2m high at Windy Point, and washed over Lagoon Road. The road was undermined and underground services were exposed along a section of road. The problem was exacerbated by further storms in July 1987, June 1989 and March 1992 (Manidis Roberts Consultants, 1993).

Various works have been undertaken near the southern end of Lagoon Beach that may have influenced (or be influencing) coastal processes, namely:

- construction of the airport runway rock revetment in 1974, which juts out about 70m on to Lagoon Beach;
- protective works (such as 44 gallon drums and gabions) constructed at Windy Point in the late 1980's[8];
- placement of about 8,000m^3 of sand (sourced from Blinky Beach) at Windy Point in 1991, with the specific extent of sand placement and subsequent direction of movement of sand not known;
- construction of a Seabee revetment (supported by sheet piling) in 1999 along about 300m of foreshore north of the runway revetment;
- rock reinforcement of the runway revetment at the northern end of Cobbys Beach in 1999;
- some placement of rock, concrete and sand to the north of the Seabee revetment in around 2004;
- construction of a sand-filled geotextile container (bag) wall in 2011 along about 20m of foreshore immediately north of the Seabee revetment; and
- beach scraping on Lagoon Beach in various forms for several decades.

It can be noted that the Seabee revetment was not put forward as a preferred solution to erosion in the Windy Point area in numerous investigations in the 1980s and 1990s (and nor was anything similar). Preferred solutions that were developed included:

- realigning Lagoon Road landward (Public Works Department [PWD] (1989)[9]; Manidis Roberts Consultants, 1993); and
- using 44 gallon drums as protective works, buried under a sandy dune (CMPS & F Environmental, 1996).

In December 1990, Manidis Roberts Consultants [Manidis Roberts] was engaged by the Board to prepare an environmental impact report for foreshore erosion works at Windy Point and the Airstrip, which was eventually documented in Manidis Roberts (1993). They noted that erosion had been

[7] The term "cyclones" was likely to be referring to storms relating to low pressure systems, not tropical cyclones alone (some, generally older, texts term all low pressure systems as "cyclones"). See Section 7.3 for further discussion on the nature of storms that cause large waves at Lord Howe Island.
[8] Ongoing erosion in the Windy Point area necessitated construction of this a drum and gabion wall, with the ongoing threat to Lagoon Road ultimately leading to construction of a Seabee revetment, and removal of the drum and gabion wall. The drum and gabion wall extended over a distance of about 50m, based on Figure 8 of Manidis Roberts Consultants (1993).
[9] PWD (1989) considered a range of options to prevent erosion at Windy Point and also south of the runway revetment. Beach scraping was not recommended except in case of an emergency. South of the runway revetment, it was recommended that the revetment was extended to prevent further erosion. A short term beach nourishment program (using Blinky Beach sand) was considered to be potentially appropriate if formulated as an interim measure.

occurring to the north (near Windy Point[10]) and immediately south of the runway revetment. To mitigate against this erosion, it was proposed to realign up to 300m of Lagoon Road up to 12.5m landward (north of the runway revetment)[11], and to replenish the area immediately south of the revetment with sand (repeated as required in future years, expected to be about 1,000m^3/year)[12].

Hard structural options (seawalls/revetments, groynes, breakwater, boulder beach, roadway on a beach) were not preferred because of higher cost and greater impacts on visual quality and recreational use of the beach. Local rock from Little Island was considered for use as a revetment, but was rejected on the advice of the Department of Planning at that time because the area was an Environment Protection Zone, and excavation was prohibited by the Lord Howe Island Regional Environmental Plan.

In March 1992, storm waves from the south west (related to *Cyclone Betsy*) eroded about 3m of bank at the southern end of the runway revetment (Manidis Roberts, 1993). Manidis Roberts (1993) also noted that the most southern 60m of the runway rock revetment had slumped due to progressive beach erosion since 1984.

Manidis Roberts (1993) considered what had caused the erosion north and south of the runway revetment and stated that:

- for most of the time, only small waves occurred in the Lagoon;
- however, during severe storms, large waves entered the Lagoon and caused erosion;
- the runway revetment construction (which extended into the Lagoon) had interrupted “the movement of sand in either direction along the beach”;
- in particular, the revetment had restricted the supply of sand from the northern side to the southern side of the revetment (as would have occurred prior to construction), thus accelerating erosion on the southern side of the revetment; and
- storms from the south west had the potential to cause erosion of the area to the south of revetment.

Manidis Roberts (1993) also noted that the southern end of Cobbys Beach had been prograding (as a changed behaviour) since 1984, at a rate of about 2,200m^3/year. This was considered to be due to increased erosion south of the runway revetment being the source of sand (transported alongshore). Sand was expected to be used to nourish the eroding area south of the revetment by being transported from the southern end of Cobbys Beach.

Manidis Roberts (1993) considered that the Windy Point area was of high visual quality and very sensitive to changes in visual character because it was visible from the main road, a large proportion of lookouts, and aircraft.

[10] With Lagoon Road within 2.3m of the erosion escarpment at Windy Point at that time. The relocation was expected to have a lifespan of 10 to 25 years based on predicted average and worst case recession rates. A 40m stretch would not have been able to be relocated the full 12.5m setback due to adjacent steep terrain (near a disused quarry at Windy Point). It was noted that natural basalt bedrock would be expected to provide some protection of the road in this area.

[11] With underground services such as electricity, telephone and airport communications relocated to the landward side of the road.

[12] This option was considered to be a short term solution to provide time while additional investigations were undertaken. The initial source of sand was to be sand that had been removed from Blinky Beach and stockpiled on the south western side of the runway near Cobbys Beach. The ongoing source of sand was to be from an accreting sandy (unvegetated) beach area about 300m alongshore and 20m cross-shore at the southern end of Cobbys Beach.

Tender documentation for construction of the Seabee revetment and related works was provided in Patterson Britton & Partners (1998). The description of the works was as follows:

- a 310m long (1:2 slope, vertical:horizontal) revetment consisting of concrete armour (Seabee) units, rock underlayer, grout injected collapsible block mattress toe and a concrete wave return wall on the crest (with a crest level of 5.5m AHD);
- road reconstruction over a length of approximately 340m involving placement of a base course and three coat bitumen seal;
- stormwater drainage with an outlet through the runway rock revetment;
- additional rock placement over the existing runway rock revetment;
- rock fall fence; and
- removal of existing bank protection works including 44 gallon drums and a small section of reno mattress.

The concrete that was placed immediately north of the Seabee revetment in around 2004 was an attempt to prevent erosion exposing sheet piling supporting the Seabees at the end of the wall (Nicholas Holt, former Manager Infrastructure & Engineering Services from the Board, personal communication) . This concrete has been replaced back into position after movement about 2 to 3 times per year with beach scraping undertaken to reinstate the dune after erosion.

Based on discussions with Nicholas Holt and Kate Dignam from the Board's Administration, it is understood that:

- when the sand-filled geotextile container (bag) wall was constructed, the sand to fill the bags was mainly taken from the immediate works area, particularly utilising sand excavated from the dune that was removed to provide a foundation for the bags (which extend below typical beach levels);
- 110 bags were used each of 2.5m^3 volume, which means that up to about 275m^3 of sand was used to fill the bags; and
- although design drawings prepared by International Coastal Management (Drawings LHI-EPW-001 to 003, dated 19 April 2011) indicated that a dune was reinstated over the bag wall after its construction (with placement of in the order of 2,000m^3 of sand), this was not undertaken.

After completion of the bag wall in May 2011, the concrete blocks originally placed in 2004 were placed immediately north of the bags at the toe of the dune. The concrete moved under wave action and was put back into position in October 2011, and then again in May 2012. A view of this area in August 2012, indicating that the concrete had again moved (or that dune erosion had extended further landward), is given in Figure 5.

Figure 5: Concrete north of sand-filled geotextile container wall, 28 August 2012

A view of the geotextile bag wall, Seabee revetment and runway revetment from the southern end of Lagoon Beach is provided in Figure 6. A view of the bag wall and Seabee revetment from offshore is given in Figure 7. An aerial view of the location of all of these works is depicted in Figure 8.

Figure 6: View of sand-filled geotextile container wall, Seabee revetment and runway revetment from the southern end of Lagoon Beach, 28 August 2012

Figure 7: View (left to right) of eroding dune with concrete and rock on beach, sand-filled geotextile container wall and Seabee revetment (29 August 2012)

Figure 8: Location of protective works near southern end of Lagoon Beach

4. FEATURES OF STUDY AREA

4.1 Geology

The Lord Howe Island region is the eroded remnant of a large shield volcano[13]. The underlying rocks comprise mainly basalt[14] and calcarenite[15]. The lower lying areas generally feature broad flats of alluvium and sand.

The geology of Lord Howe Island is described in Lord Howe Island Board (1987) and references therein, who noted that:

- the remnant volcano at Lord Howe Island was active about 7 million years ago, for about 0.5 million years, with the volcano formed by periodic extrusion of highly fluid lava (with flows ranging from less than one metre thick to up to 30m thick);
- once volcanic activity ceased, the volcano began to be eroded by sea and wind action, and deposition of wind-blown sand-size calcareous[16] material also occurred; and
- Lord Howe Island was located on a large undersea shelf[17], which was formed by wave action during the Pleistocene epoch[18] when sea level was much lower than at present.

Lord Howe Island Board (1987) noted that the cliffs at Neds Beach, Middle Beach and Signal Point were composed of what is known as Neds Beach Calcarenite. They described this calcarenite as a type of 'sandstone' comprised of small fragments of coralline algae[19], and lesser amounts of broken coral, shells and foraminifera[20]. They considered that this material was carried by the wind from coral reefs when sea level was much lower than at present, accumulating in dunes and later becoming compacted and cemented to form rock.

This calcarenite is extremely susceptible to weathering, with many outcrops 'honeycombed' and containing large pore spaces and 'vertical solution pipes'. However, such weathering only occurs

[13] A shield volcano is a type of volcano usually built almost entirely of spreading fluid lava flows. They are named for their large size and low profile, resembling a warrior's shield lying on the ground (Wikipedia contributors, 2014a).
[14] An igneous (volcanic) rock formed from the rapid cooling of basaltic lava.
[15] Calcarenite is a type of limestone (sedimentary rock) that is composed predominantly of detrital (transported) sand-size carbonate grains. The grains consist of sand-size grains of either corals, shells, ooids, intraclasts, pellets, or fragments of older limestones and dolomites, other carbonate grains, or some combination of these. Calcarenite is the carbonate equivalent of a sandstone (Wikipedia contributors, 2014b). Carbonate rocks (Wikipedia contributors, 2014c) are a class of sedimentary rocks composed primarily of carbonate minerals (minerals containing the carbonate ion CO_3^{2-}). The two major types of carbonate rocks are limestone (which is composed of calcite or aragonite) and dolostone (which is composed of dolomite). Calcarenite consists of grains of carbonate that have accumulated either as coastal sand dunes (aeolianites), beaches, offshore bars and shoals, turbidites, or other depositional settings.
[16] Calcareous is an adjective meaning "mostly or partly composed of calcium carbonate". Calcareous sediments are usually deposited in shallow water near land, since the carbonate is precipitated by marine organisms that need land-derived nutrients (Wikipedia contributors, 2014e). .
[17] Woodroffe (2003) noted that this shelf was 8 to 10km across and 30 to 50m deep.
[18] The Pleistocene is a geological epoch which lasted from about 2.6 million to about 11,700 years before present. Pleistocene climate was marked by repeated glacial cycles. The Pleistocene is the first epoch of the Quaternary Period with the subsequent Holocene epoch extending to the present time (Wikipedia contributors, 2014f).
[19] Coralline algae are red algae (or *Rhodophyta*) in the order Corallinales. They are characterized by a thallus that is hard because of calcareous deposits contained within the cell walls. The colours of these algae are usually pink or some other shade of red, but other species can be purple, yellow, blue, white or grey-green. Coralline algae play an important role in the ecology of coral reefs (Wikipedia contributors, 2014d).
[20] Foraminifer are a single-celled planktonic animal with a shell. Most kinds are marine, and when they die ocean-floor sediments are formed from their shells.

above the high tide water level. A rock that appears weathered may be 'solid' below the water level (Lord Howe Island Board, 1987).

Most of the beaches at Lord Howe Island (including Lagoon Beach, Cobbys Beach, Blinky Beach, Middle Beach and Neds Beach) and are almost entirely comprised of calcareous material broken off the reef. These sand sized fragments of coral, shell, and algal material become rounded and polished as they move back and forth under wave action.

There are also beaches comprised of rounded basalt boulders at Lord Howe Island, for example near Little Island.

Woodroffe et al (1995) considered that Lord Howe Island was relatively stable (in terms of vertical movement related to tectonic and hydrostatic flexural factors). This is important when considering future effects of sea level rise, as this relative stability means that sea level rise relative to the land surface is likely to be similar to sea level rise caused by changing levels of the ocean[21].

4.2 Coral Reef and Lagoon

4.2.1 Present Characteristics

The most southerly coral reef in the world[22] is located at Lord Howe Island. The reef occurs as a result of an eastward divergence of the East Australian Current (Woodroffe, 2003). The East Australian Current is discussed further in Section 7.4.

The coral reef on the western side of Lord Howe Island formed during the Pleistocene epoch, and has continued to grow during recent times (Lord Howe Island Board, 1987). The reef is about 6km long and is shore-attached at its northern and southern ends, discontinuously enclosing a Lagoon. The reef provides a substantial reduction in wave energy reaching the Lagoon shoreline.

The reef is unique given the large proportion of calcareous algae (also known as coralline algae[19]) occurring with coral. This mixture of algae and coral occurs because Lord Howe Island is affected by both warm and cold currents (Lord Howe Island Board, 1987).

Based on a hydrographic survey completed by the Australian Hydrographic Service in March 1997, the position of reef crests offshore of the Lagoon at Lord Howe Island are depicted in Figure 9. The positions of the three main reef passages are also depicted in this Figure.

All points along the reef crest lines in Figure 9 were above 0m AHD in the survey, and the average level of these reef crests was about 1.0m AHD[23], which is 0.2m below mean sea level in the Lagoon, and 0.2m above Mean Low Water Neaps[24]. However, note that the elevation of the reef crests was variable, with the average elevations along sections depicted in Figure 10 and Figure 11.

[21] Global mean sea level rise as typically reported by the Intergovernmental Panel on Climate Change is relative to the centre of the earth and hence independent of land movements.
[22] Woodroffe (2003) actually only noted that the Lord Howe Island reef was the most southerly in the Pacific Ocean. Numerous other sources (eg Woodroffe et al ,1995) state that it is the most southerly in the world.
[23] Manidis Roberts (1993) also stated that the average coral reef level was 0.9m LHITD (that is, 1.0m AHD).
[24] A water level of 1.0m AHD is exceeded for about 69% of the time in the Lagoon.

With additional reference to a hydrographic survey completed by NSW Maritime in October 2008, the locations of two deeper areas within the Lagoon (about 600m to 800m offshore of the southern end of Lagoon Beach) are also depicted in Figure 9. Elevations within these areas were below -2m AHD[25], and it would be expected that these areas would be a sink for any sediment being transported in the region given their depth relative to surrounding areas of the Lagoon. That is, these areas would be a barrier to any sediment transport. Discussions with Christo Haselden (Ranger, Environment & Community Development, Lord Howe Island Board) and Rex Byrne (owner of a yacht that is moored near these areas) would indicate that there is visual evidence of sand buildup in these areas.

Within the Lagoon, corals areas have dominant coverage in the seaward (western) portion located seaward of Blackburn Island, while the landward (eastern) portion is generally sandy floor (Veron and Done, 1979). Kennedy and Woodroffe (2000) described the Lagoon bed surface as dominated by medium-coarse grained sand with scattered coral and macro algal communities that increased in luxuriance towards the reef crest.

Kennedy and Woodroffe (2000) noted that centimetre-high sand ripples occurred across the bare sand surfaces in the central Lagoon, indicating mobilisation of the surface sediments by waves and tidal currents.

[25] With the more southern of these deeper areas incorporating Comets Hole, which has a bed elevation of about -7m AHD.

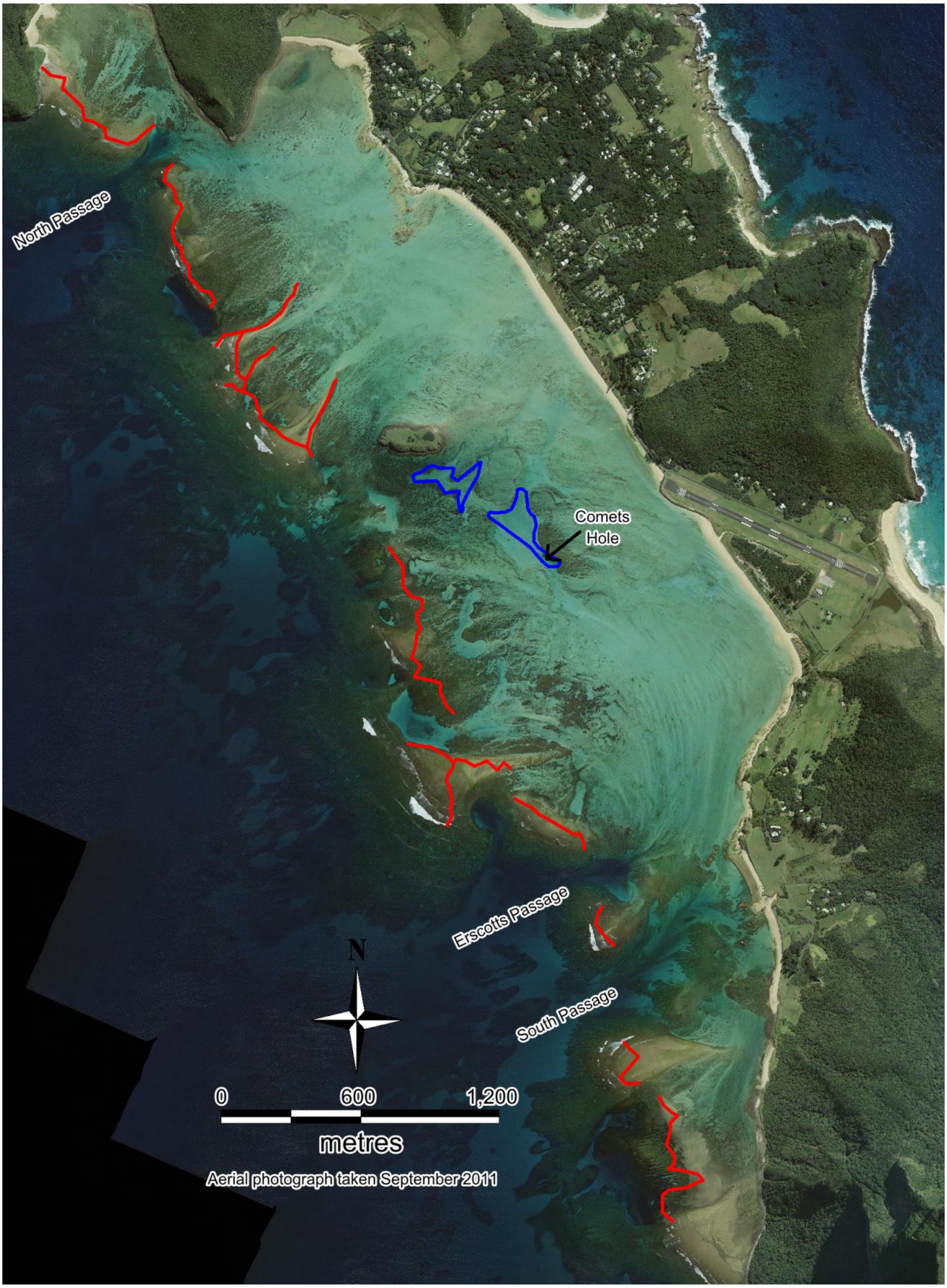


Figure 9: Position of reef crests adjacent to Lagoon (red), and location of relatively deep holes (blue)

Figure 10: Position and elevation (m AHD) of reef crests north of Blackburn Island (red), with portion of deeper Lagoon area shown in blue

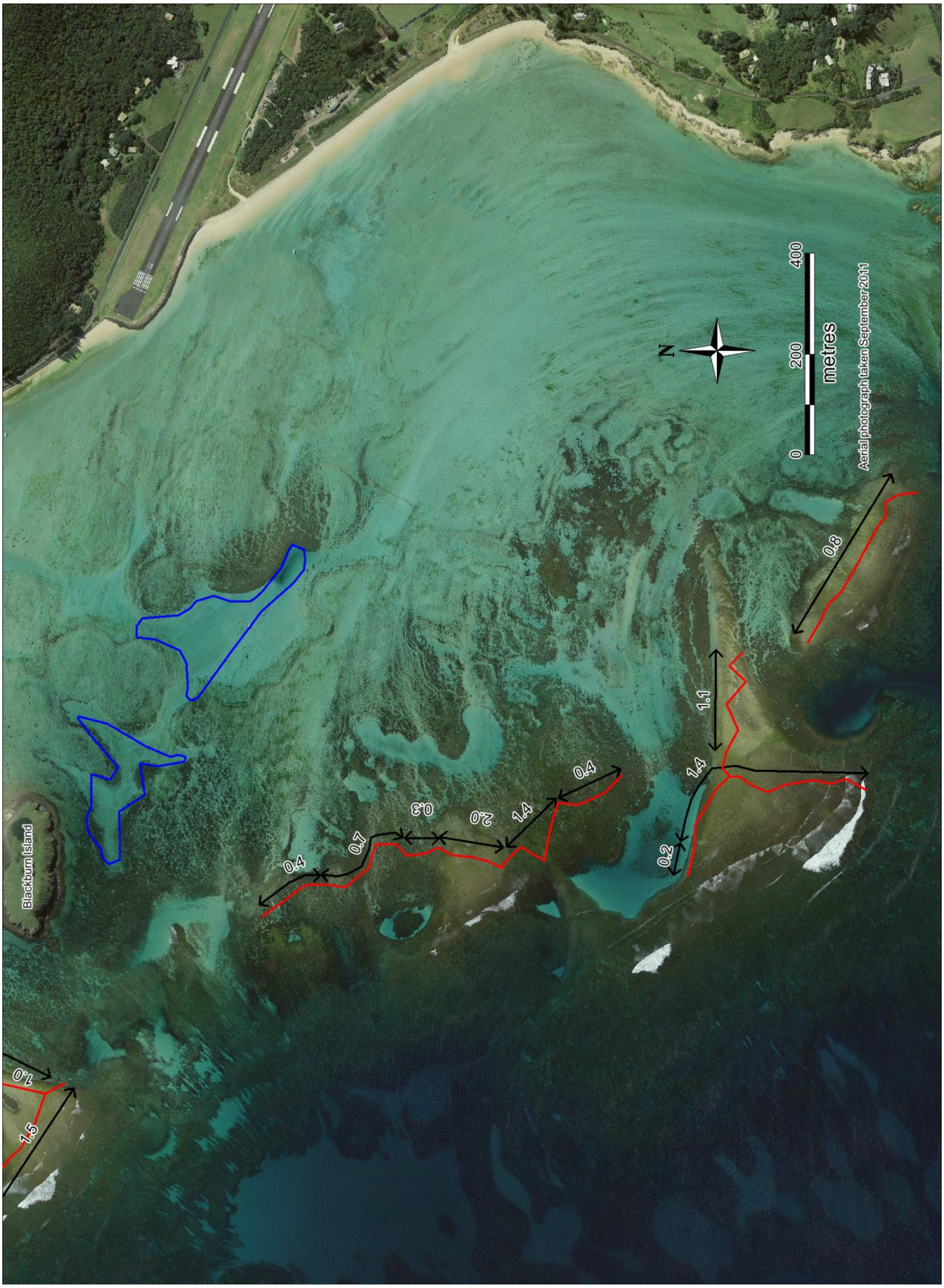


Figure 11: Position and elevation (m AHD) of reef crests south of Blackburn Island (red), with deeper Lagoon areas shown in blue

4.2.2 Coral Reef Processes

In discussing coral reef processes it is important to realise the dominant role of biological factors in reef development, and also the importance of understanding these processes for coastal management. Coral reefs are complex ecosystems, which have high diversity and productivity, an interdependence of animals and other organisms, and many symbiotic relationships (Harvey and Caton, 2010). As Harvey and Caton (2010) describe further:

- reef-building (hermatypic) corals have zooxanthellae, which are minute unicellular algae living within the coral tissue, and these have a symbiotic relationship with the coral polyp by assisting it to lay down its skeleton (a corralite) through photosynthesis, taking up polyp wastes, and supplying the coral with about 98% of its food requirements;
- over thousands of years the build-up of corallite forms a porous limestone which is the basis for reef building, along with calcareous algae;
- growth rates of corals are fastest in shallow, well-lit waters, and can be up to 20mm/year for massive corals and up to 100mm/year for branching corals;
- coral reefs depend on other organisms, particularly algae, which are the primary energy source through photosynthesis;
- there are also crustose corraline algae which are important reef-builders, and in some places algae can form up to 80% of reef sediments, particularly the platey *Halimeda*;
- boring algae are important in reef breakdown;
- corals have an asexual reproduction phase involving major spawning events;
- corals grow in warm water down to a depth of 100m, where they become light limited, and other factors restricting their growth are excessive freshwater and sediment deposition;
- there is great variation in coral growth rates, depending on the position of the reef surface relative to sea level, and vertical reef growth may be negligible on most reef surfaces that are exposed at low tide;
- vertical reef growth will also be significantly altered once it comes directly under the modifying influence of surface wave conditions, and it has been observed that most reef flats are between 100m and 400m wide; and
- another important factor in reef growth is the role of corraline algae.

Reefs are composed almost entirely of skeletal carbonate sediments produced by marine plants and animals (that is, biogenic sediments), incorporated either as the rigid framework or as unconsolidated detrital (eroded and transported) sediments (Woodroffe, 2003). The process of reef growth is complex, involving calcification by the organisms that contribute to reef, various stages of breakdown[26], transport, redistribution and cementation (Woodroffe, 2003). Woodroffe (2003) noted that numerous higher latitude (more southerly) reefs in Australia, including at Lord Howe Island, showed a similar pattern of colonisation and vertical reef growth to more tropical reefs.

Harriott et al (1995) completed a quantitative survey of the reef communities at Lord Howe Island, against which future anthropogenic impacts and natural disturbances could be assessed, and to determine whether the coral communities had changed in the 16 years since the only previous survey by Veron and Done (1979). It is recommended that ongoing monitoring and management of these coral communities is undertaken.

[26] Erosion occurs by physical processes, including wave damage, as well as biological processes (such as grazing and boring organisms).

4.2.3 Long Term Evolution

Martin et al (2014) analysed sediments that have accumulated in four Lord Howe Island coastal wetlands over the last 5,500 years[27]. They found that sediment began to accumulate over basalt bedrock about 4,500 calibrated years before 1950[28], with greater sediment availability after 2,800 calibrated years before 1950 as sediment filled sinks in the Lagoon floor and reached a shallow enough depth to be reworked by waves.

Kennedy and Woodroffe (2000) estimated that by 4,000 radiocarbon years before present most of the Lagoon had accreted to a level close to the modern Lagoon bed surface, having accumulated (in the preceding 2,500 years) over 11m of sediment in the northern part of the Lagoon and possibly up to 30m in the southern part.

Martin et al (2014) considered that increasing westerly wind strength from 600 calibrated years before 1950, combined with falling sea levels[29] and this lagoon infilling, facilitated increased sediment movement from the reef crest and the Lagoon bed to the western shore of Lord Howe Island. They noted that this caused rapid growth of the coastal plain (development of beaches) at about 500 calibrated years before 1950.

Kennedy and Woodroffe (2000) considered that the only features of the Lagoon still experiencing sediment infill were at various “holes” such as Comets Hole and Sylphs Hole. Martin et al (2014) suggested that these holes could be affecting sediment transport within the Lagoon and delaying shoreline accretion at nearby locations by acting as a sink for sediment moving between the reef crest and shoreline. Haskoning Australia independently came to the same conclusion by observation of bathymetric and sediment features in the Lagoon (Section 4.2.1).

Colin Woodroffe (School of Earth and Environmental Sciences, University of Wollongong, personal communication) considered that sediment may still be moving landward across the Lagoon bed and adding to subaerial beach sediments.

4.3 World Heritage Listing

The Lord Howe Island Group was included in the World Heritage List in 1982, as “an outstanding example of oceanic islands of volcanic origin containing a unique biota of plants and animals, as well as the world’s most southerly true coral reef” (UNESCO World Heritage Centre, 2014).

All World Heritage properties in Australia are ‘matters of national environmental significance’ protected and managed under national legislation, namely the *Environment Protection and Biodiversity Conservation Act 1999*.

[27] With years reported by Martin et al (2014) as calibrated radiocarbon ages before the year 1950 AD, and denoted as “calibrated years before 1950” herein. Calibrated years are identical to calendar years (Dr Scott Mooney, School of Biological, Earth and Environmental Sciences, personal communication), so for example 500 calibrated years before 1950 was a calendar year of 1450 AD.

[28] Kennedy and Woodroffe (2000) estimated that sediments were first deposited in the Lagoon about 6,500 radiocarbon years before present, with growth of the reef crest between 6,000 and 5,000 radiocarbon years before present causing a reduction in wave energy in the Lagoon and facilitating sediment deposition.

[29] Martin et al (2014) considered that sea level may have been 1.5m higher about 2,000 calibrated years before 1950. Woodroofe et al (1995) similarly noted sea levels about 1m to 1.5m higher than present around 3,000 years ago, and probably still 1m above present levels around 900 years ago.

As further noted by UNESCO World Heritage Centre (2014):

- "The Lord Howe Island Group is grandiose in its topographic relief and has an exceptional diversity of spectacular and scenic landscapes within a small area, including sheer mountain slopes, a broad arc of hills enclosing the lagoon and Balls Pyramid rising abruptly from the ocean.
- It is considered to be an outstanding example of an island system developed from submarine volcanic activity and demonstrates the nearly complete stage in the destruction of a large shield volcano. Having the most southerly coral reef in the world, it demonstrates a rare example of a zone of transition between algal and coral reefs. Many species are at their ecological limits, endemism is high, and unique assemblages of temperate and tropical forms cohabit.
- The islands support extensive colonies of nesting seabirds, making them significant over a wide oceanic region. They are the only major breeding locality for the Providence Petrel (*Pterodroma solandri*), and contain one of the world's largest breeding concentrations of Red-tailed Tropicbird (*Phaethon rubricauda*).
- The Lord Howe Island Group is an outstanding example of the development of a characteristic insular biota that has adapted to the island environment through speciation. A significant number of endemic species or subspecies of plants and animals have evolved in a very limited area. The diversity of landscapes and biota and the high number of threatened and endemic species make these islands an outstanding example of independent evolutionary processes.
- Lord Howe Island supports a number of endangered endemic species or subspecies of plants and animals, for example the Lord Howe Woodhen, which at time of inscription was considered one of the world's rarest birds. While sadly a number of endemic species disappeared with the arrival of people and their accompanying species, the Lord Howe Island Phasmid, the largest stick insect in the world, still exists on Balls Pyramid. The islands are an outstanding example of an oceanic island group with a diverse range of ecosystems and species that have been subject to human influences for a relatively limited period.

UNESCO World Heritage Centre (2014) noted that key threats requiring ongoing attention include fishing; tourism; invasive animals, plants and pathogens; and anthropogenic climate change. The latter is significant to the consideration of coastal processes and coastline hazards herein.

4.4 Land Use

The entire Lord Howe Island foreshore is zoned as either "Zone No. 7 – Environment Protection" or "Zone No. 8 – Permanent Park Preserve" in the *Lord Howe Island Local Environmental Plan 2010*. A Foreshore Building Line also applies along the Lagoon foreshore, and from Neds Beach to Middle Beach inclusive on the eastern foreshore.

Most of the foreshore is also Crown Reserve, except for a length of foreshore south of Cobbys Beach which has a number of Portions or Lots used for recreation and agriculture/grazing as Special Leases.

Under Section 31A of the *Lord Howe Island Act 1953*, the Minister may grant permission to occupy crown land or vacant crown land, known as Permissive Occupancy. For example, the boatsheds at the northern end of Lagoon Beach, the Aquatic Club and Pinetrees boatshed are all Permissive Occupancies. Improvements on Permissive Occupancy land are generally privately owned.

5. PLANNING FRAMEWORK

Lord Howe Island is part of New South Wales. Although administered under the *Lord Howe Island Act 1953*, it comprises Crown Land and is subject to the provisions of the:

- *Crown Lands Act 1989*;
- *Environmental Planning & Assessment Act 1979*; and
- *Roads Act 1993* (NSW Land & Property Information, 2014).

All land on the island is vested in the Crown, under the management of the Lord Howe Island Board. Islanders (those persons so deemed in Section 3 of the *Lord Howe Island Act 1953*) may be granted a lease in perpetuity for residential purposes (NSW Land & Property Information, 2014).

Land may also be reserved or dedicated to the public by the publication of a notification in the Government Gazette by the Minister Administering the *Lord Howe Island Act 1953*. Special leases, not exceeding 10 years, may also be granted to Islanders for grazing, cultivation or other approved purposes (NSW Land & Property Information, 2014).

The Lord Howe Island Board is the consent authority for all development and subdivision activity that takes place on the island (NSW Land & Property Information, 2014).

Lord Howe Island (in its entirety) is within the “coastal zone” as defined in the *Coastal Protection Act 1979*, as shown on maps outlining the coastal zone[30].

[30] Specifically “New South Wales Coastal Policy 1997, Map 41 of 117” prepared by the Department of Urban Affairs and Planning.

6. COLLECTION AND REVIEW OF DATA

6.1 Aerial Photography and Photogrammetric Data

A review of aerial photography and photogrammetric data from Lagoon Beach and Cobbys Beach is provided in **Appendix B**. To summarise, rates of change of volume per year in various compartments along Lagoon Beach and Cobbys Beach (based on data from 5 dates from 1965 to 2011 and measured above 0m AHD) were as depicted in Figure 12.

It is evident that most of length of the beaches along the Lagoon at Lord Howe Island (Lagoon Beach north of the runway, and Cobbys Beach south of the runway) have been growing in sand volume or moving seaward (prograding). The only two areas reducing in volume or moving landward (receding) are located immediately north and south of the runway revetment, Seabee revetment, and bag wall structures. This is depicted in Figure 12.

Lagoon Beach has been approximately in balance (gain in the north about equal to the loss in the south, of magnitude around 550m^3/year), while the gain at the southern end of Cobbys Beach exceeds the loss at the north of that beach by about 460m^3/year. These volumes are calculated above Australian Height Datum (0m AHD), with the mean Lagoon water level equal to about 1.2 m AHD.

Review of aerial photography provides evidence that sediment is naturally mobile in the wider Lagoon and may be building up over reef areas within the Lagoon. An example of far less distinct reef features in 2011 compared to 2001 (which may be from smothering by sediment) is depicted in Figure 13 (northern end of Lagoon Beach) and Figure 14 (Cobbys Beach), at identical locations and scales for both years at each site.

Further investigation of the sources and transport direction of sediment in the wider Lagoon would be warranted to inform a longer term understanding of coastal processes and to inform the design of any future beach nourishment campaigns or other works. A preliminary conceptual model of sediment transport processes that is an attempt to document the observed beach changes and is consistent with observed circulation patterns is developed in Section 7.8.

Figure 12: Summary of long term (1965 to 2011) sand volume changes at Lagoon Beach and Cobbys Beach

Figure 13: Evidence of sediment smothering reef areas at northern end of Lagoon Beach (2001 top, and 2011 bottom), with main areas of potential smothering within red boxes

Figure 14: Evidence of sediment smothering reef areas at Cobbys Beach (2001 top, and 2011 bottom), with main area of potential smothering within red box

6.2 Sediment Data

Coastal sediments may be of either terrigenous (land) origin or biogenic (living) origin. In the former case, they often are formed predominantly of silica sand. In the latter case they are predominantly calcium carbonate derived from marine organisms, either directly from detrital skeletal material and shells or indirectly from limestone rocks (NCCOE, 2012).

At Lord Howe Island, 99% of the beach and lagoon sediments were found to be composed of skeletal carbonates. Analysis of sediment samples that were collected from beaches and the Lagoon at Lord Howe Island is provided in **Appendix C**. Samples were collected in August 2012 and May 2013.

The sample locations from August 2012 and May 2013, and median particle size (d_{50}) of the tested samples, are depicted in Figure 15 (northern end of Lagoon Beach), Figure 16 (southern end of Lagoon Beach) and Figure 17 (Cobbys Beach). Kennedy (1999) has also analysed samples from the Lagoon area, and his mean particle size testing results[31] are also depicted in these Figures. Note that all particle sizes are shown in microns (that is 10^{-6}m or μm, where 1mm equals 1000μm).

Extensive spatial sediment transport pathways could be inferred from the particle size testing results. That is, there was evidence of the continuity of the Lagoon bed and beaches, with sediment being transported from the Lagoon to the beaches. Coarser sediments were generally evident near the waterline, but otherwise there were generally similar sizes in the Lagoon and on the beach. Some of the finer sediments were at Cobbys Beach, which may be evidence of its general progradation in recent years.

Given the postulated significant infeed (onshore transport) of lagoonal sediments on to Lagoon Beach and Cobbys Beach in around 1450 AD (Section 4.2.3), and general similarity of the Lagoon and beach sediments, it can be postulated that sediments on the Lagoon bed may still be moving onshore at these beaches. Indeed, the review of photogrammetric data (Section 6.1) indicated that most of the length of these beaches has prograded over the last 50 or so years, and aerial photography (Section 6.1) gives evidence of sediment mobility in the Lagoon.

[31] Note that Kennedy (1999) used a method of Folk and Ward (1957) to determine the mean grain size, in which the mean size was determined as $(d_{16}+d_{50}+d_{84})/3$, where d_{16} and d_{84} are the 16th and 84th percentile particle sizes respectively.

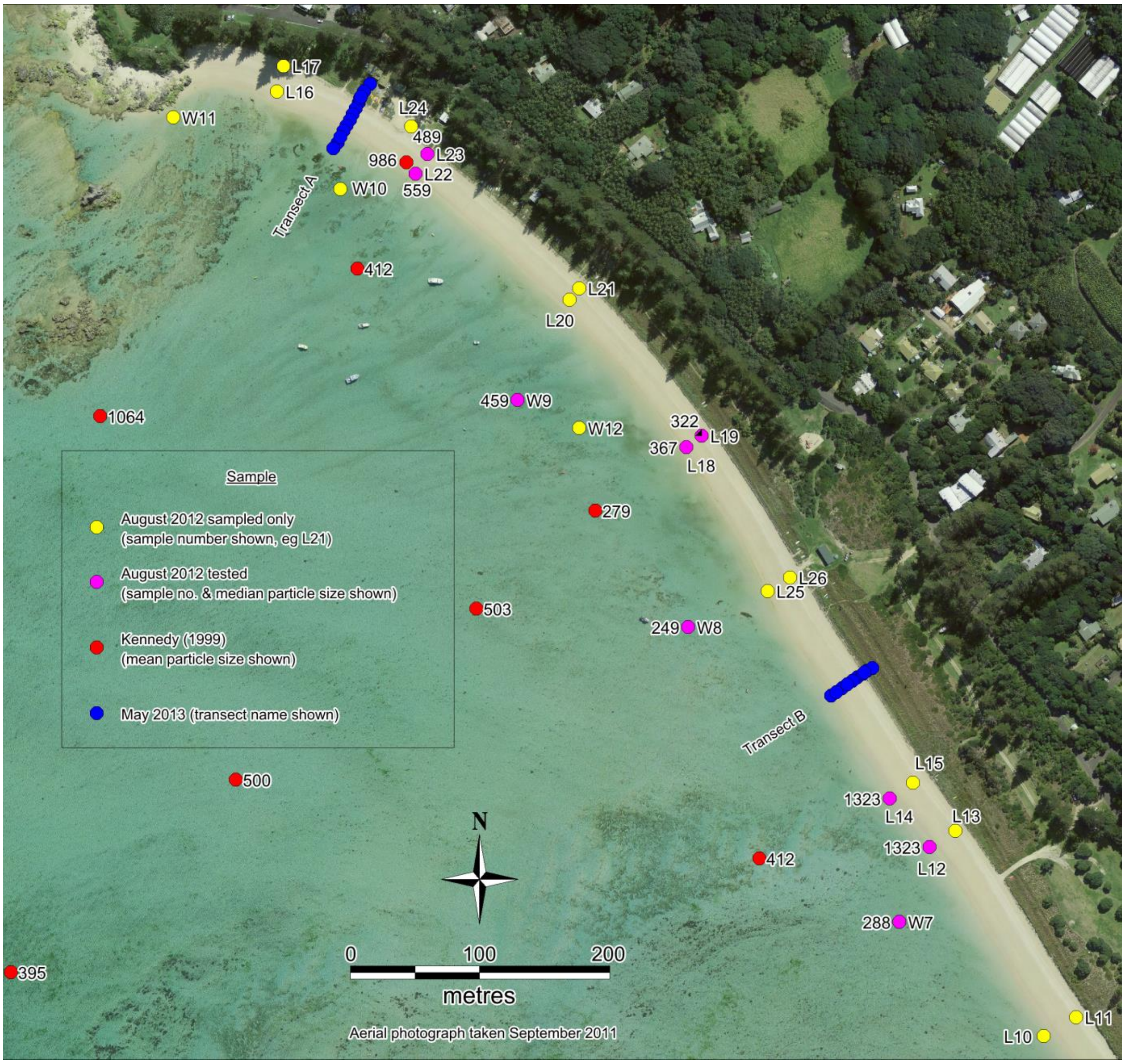


Figure 15: Sample locations and particle sizes (in microns) at north end of Lagoon Beach

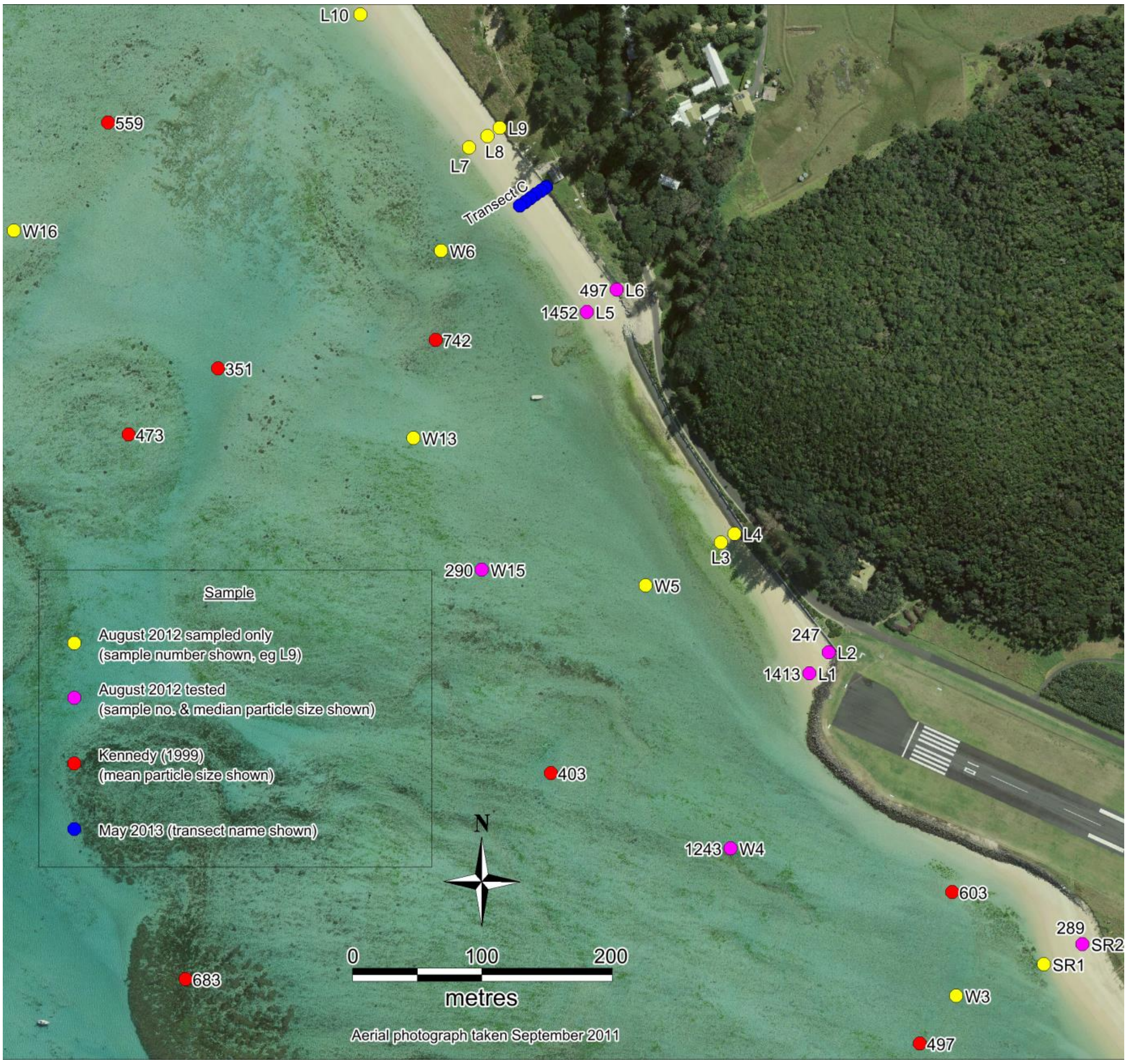


Figure 16: Sample locations and particle sizes (in microns) at south end of Lagoon Beach and adjacent to runway revetment

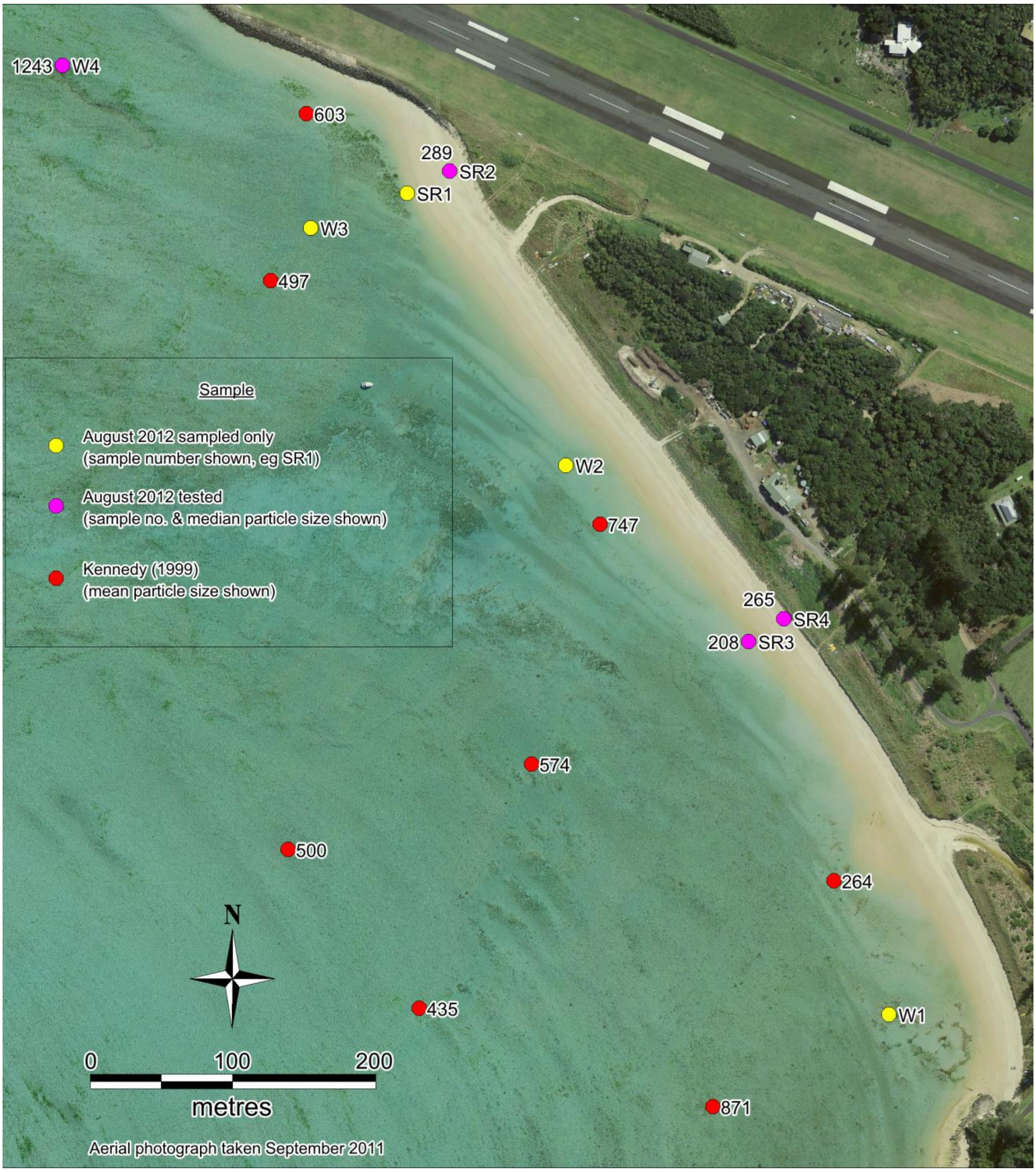


Figure 17: Sample locations and particle sizes (in microns) at Cobbys Beach

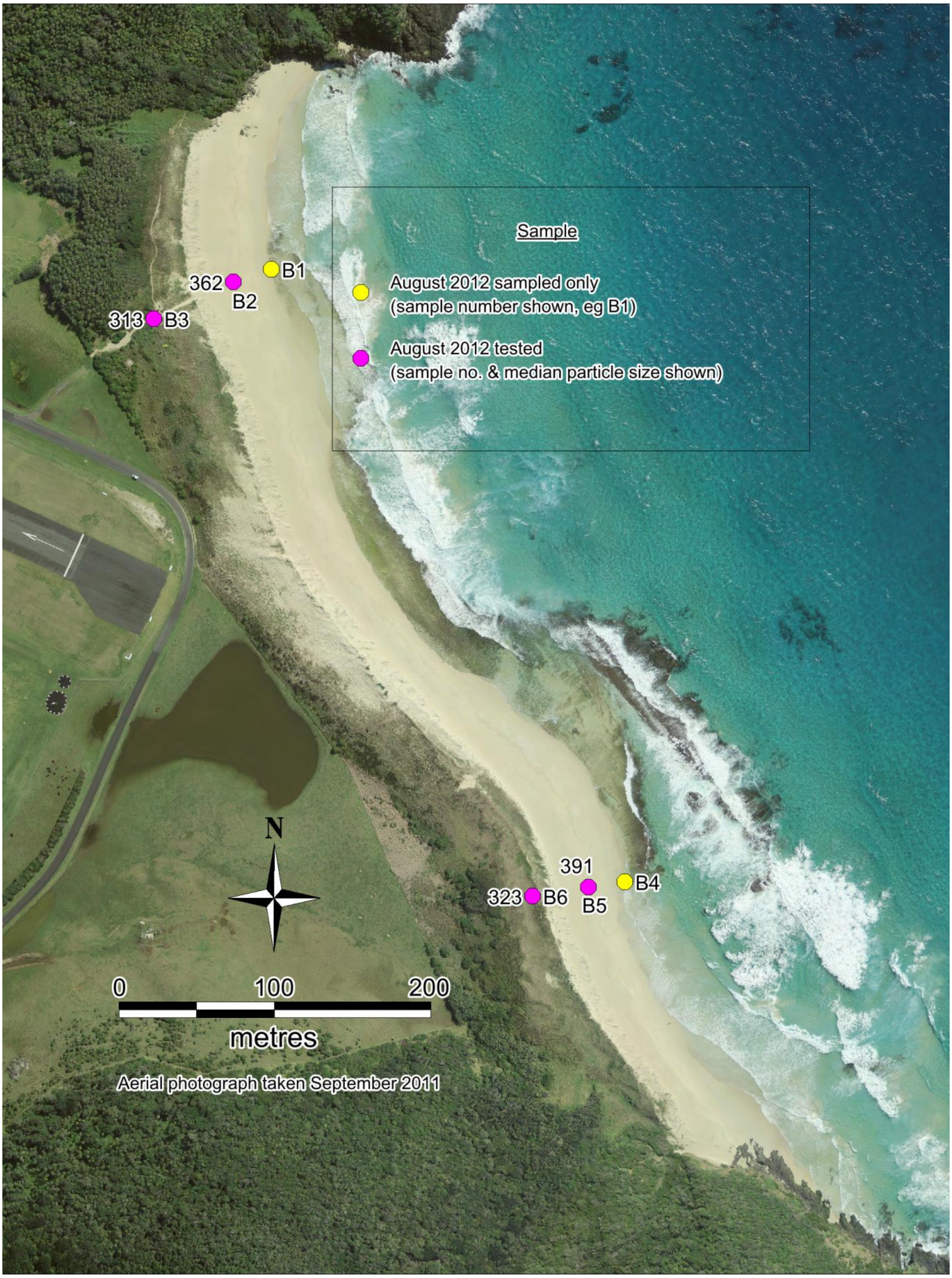


Figure 18: Sample locations and particle sizes (in microns) at Blinky Beach

6.3 Hydrographic (Bathymetric) Data

The two most recent extensive hydrographic (bathymetric) surveys of the Lagoon area at Lord Howe Island were completed by:

- the Australian Hydrographic Service in March 1997; and
- NSW Maritime in October 2008 (see Figure 19).

The shallowness of the Lagoon, particularly east of Blackburn Island, is evident in Figure 19.

Patterson Britton & Partners (1998) also depicted Lagoon bed contours in 1990. The Australian Hydrographic Office hydrographic chart covering Lord Howe Island is AUS 610.

Based on the 2008 data, two cross sections through the Lagoon (at the locations shown in Figure 20) are depicted in Figure 21.

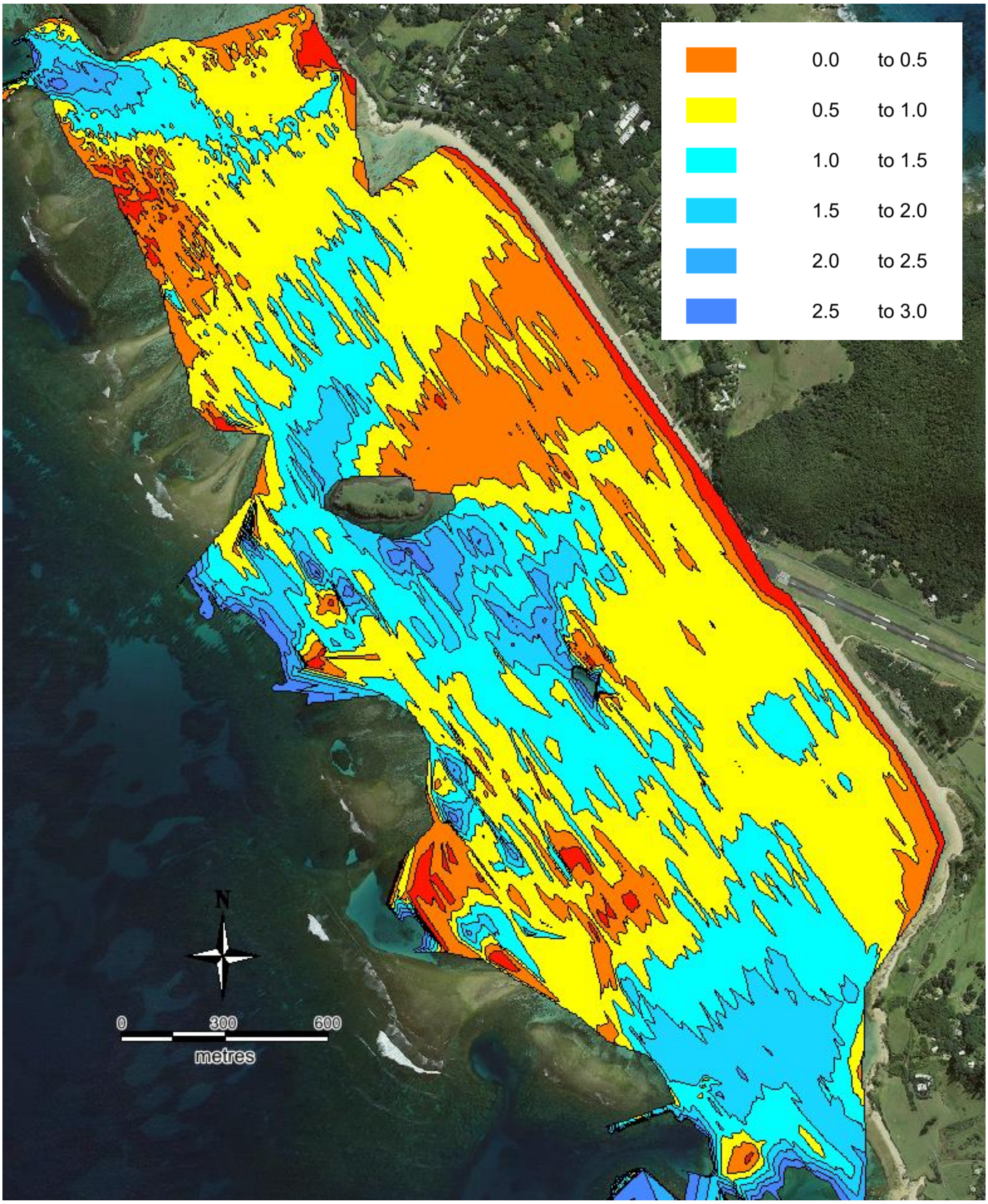


Figure 19: Bathymetric contours at 1m interval derived from 2008 survey, with depths shown relative to AHD (red areas are above 0m AHD)

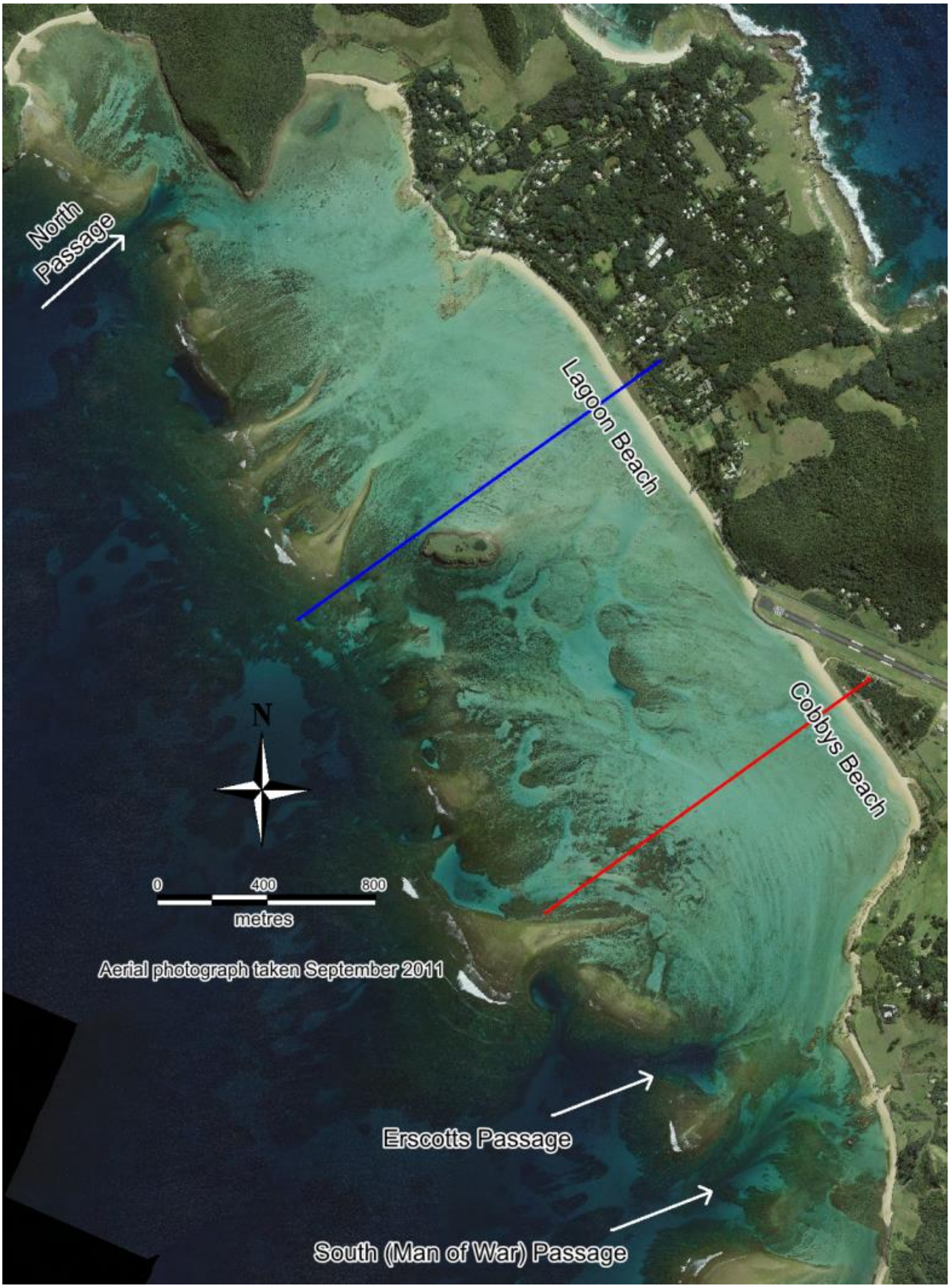


Figure 20: Locations of northern and southern profiles across Lagoon bed, depicted in cross section in Figure 21

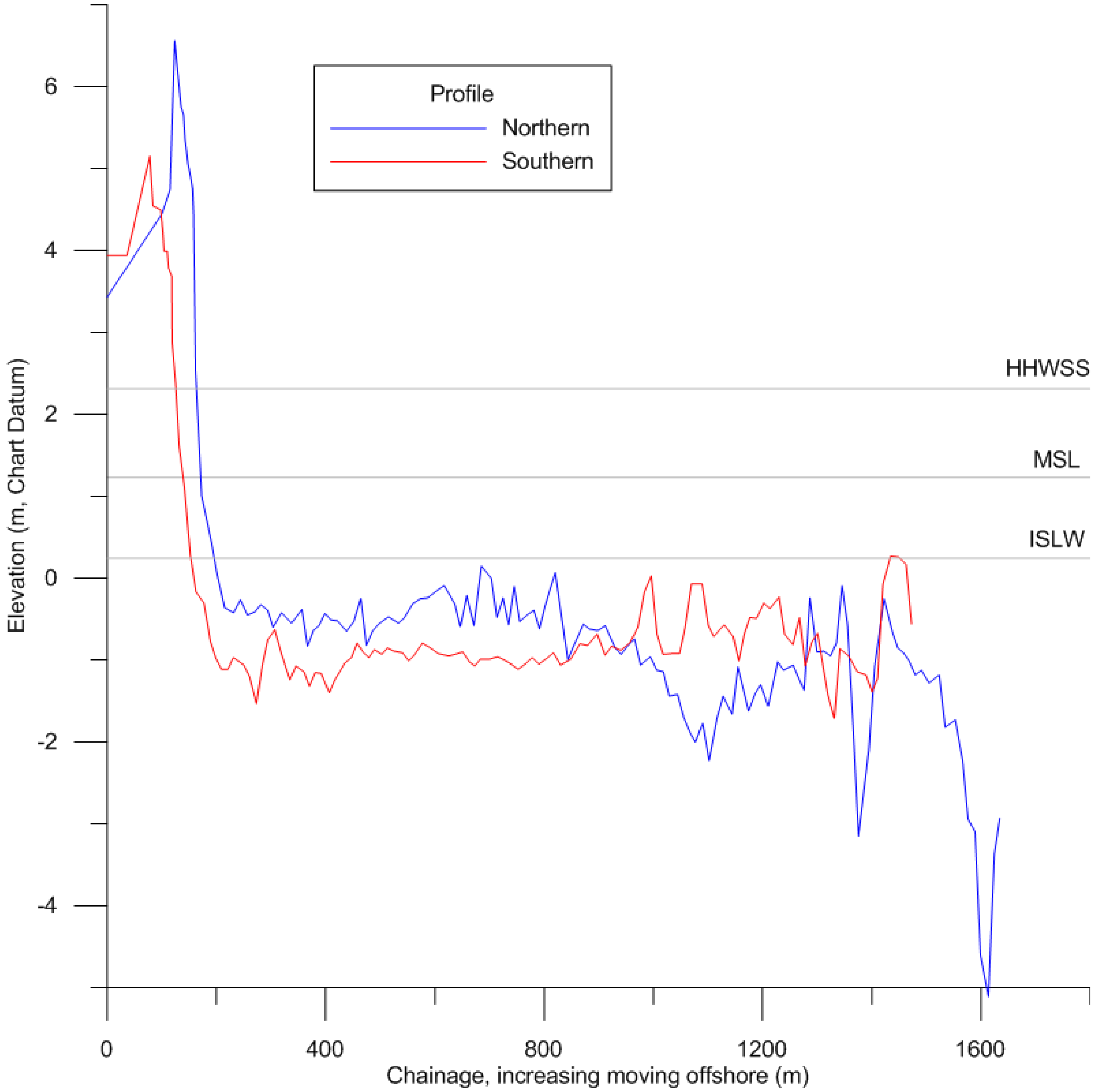


Figure 21: Example cross sections through dune and Lagoon, with profile locations depicted in Figure 20

6.4 Water Levels

Water levels in the Lagoon vary with astronomical tide and other processes, with water flowing (mainly out) through the three main reef passages (Figure 4) and in via wave overtopping and direct oceanic ingress over the coral reef at higher stages of the tide (with the reef crest being about 0.2m below mean sea level on average).

Manly Hydraulics Laboratory (MHL) has operated a water level recorder at the jetty at Lord Howe Island since 1994 on behalf of OEH. Based on review of data collected every 15 minutes from 1994 to 2013, various statistics were derived including tidal planes (Table 1) and exceedance probabilities

(Table 2). From this analysis, the mean neap range is 0.85m, and the mean spring range is 1.55m. The highest water level recorded was 2.84m AHD on 14 July 1995. The largest positive residuals in the record (where measured water levels were above predicted tide levels) were found to be about 0.8m.

Table 1: Tidal planes in Lagoon at Lord Howe Island

Tidal plane	Water level (m AHD)
High High Water Solstice Springs	2.31
Mean High Water Springs	2.01
Mean High Water	1.83
Mean High Water Neaps	1.66
Mean Sea Level	1.23
Mean Low Water Neaps	0.81
Mean Low Water	0.63
Mean Low Water Springs	0.46
Indian Springs Low Water	0.24

Table 2: Exceedance probabilities for water levels in Lagoon at Lord Howe Island

Probability of exceedance (%)	Water level (m AHD)
0.1	2.53
1	2.30
5	2.05
10	1.91
50	1.23
90	0.58

Besides astronomical tide, water levels in the Lagoon at Lord Howe Island are strongly dependent on regional oceanographic circulation patterns. The Bureau of Meteorology provides forecasts of sea level anomalies (and other parameters such as sea surface temperature) based on an Ocean General Circulation Model and real-time observations, known as BLUElink Ocean Forecasts produced by the *Ocean Model, Analysis and Prediction System* version 2.0 (OceanMAPSv2.0).

As described by Bureau of Meteorology (2014a), variations in the elevation of the ocean are mainly caused by the earth's rotation and changes in water density at depth. A phenomenon that has a dominant influence on the general circulation of the ocean is the so-called 'eddy'. This term refers to a cyclonic motion (in the form of a vortex) on the scale 10 to 200km in diameter that forms, propagates throughout the ocean and later decays. Throughout this cycle the eddies redistribute heat and salt. Common forms of eddies found in the Australian region are 'warm-core' and 'cold-core' eddies (where the interior of the eddy is either warmer or colder than the surrounding ocean respectively). A warmer, less dense water column has a larger specific volume leading to an increase in surface height and pressure compared to the surrounding ocean. In the presence of the earth's rotation, this pressure gradient radiating out from the warm core of the eddy is 'geostrophically' balanced by vortical currents circulating around the core. The term 'geostrophic' refers to the situation where, for an observer on the earth's surface, the vortical currents (the circulating currents flowing around the eddy) induce an equal and opposite Coriolis force to balance the gradient in pressure. A warm-core eddy, which has a pressure gradient radiating out, leads to anticyclonic motion, which is anticlockwise in the southern hemisphere. A cold-core eddy has a pressure gradient force that is focused toward the core, which leads to cyclonic motion that is clockwise in the southern hemisphere. Good examples of these can be found in the Tasman Sea as part of the East Australian Current. The change in density between the eddy core and the surrounding ocean can be detected as a change in the surface height of the ocean of the order of one metre.

An example of sea surface temperature and sea level anomaly results from BLUElink is provided in Figure 22 for offshore of NSW (including Lord Howe Island), and in Figure 23 for a more zoomed in area surrounding Lord Howe Island. The considerable variability in sea level is evident, for example where Lord Howe Island has a sea level anomaly of -0.2m, and a few hundred kilometres towards the mainland there is a sea level anomaly of +0.5m (that is, 0.7m higher).

A plot of the daily average water level at Lord Howe Island (as measured by MHL) versus the sea level anomaly at Lord Howe Island (from BLUElink) is provided in Figure 24 for the April 2011 to February 2013 period[32]. It is evident that the daily average water level at Lord Howe Island is strongly influenced by the regional oceanographic water level.

[32] The assistance of Mr Ben Modra of MHL in providing the plotted data is gratefully acknowledged. The measured data was normalised against the full record average, and the BLUElink data was adjusted to have the same average water level as the measured data.

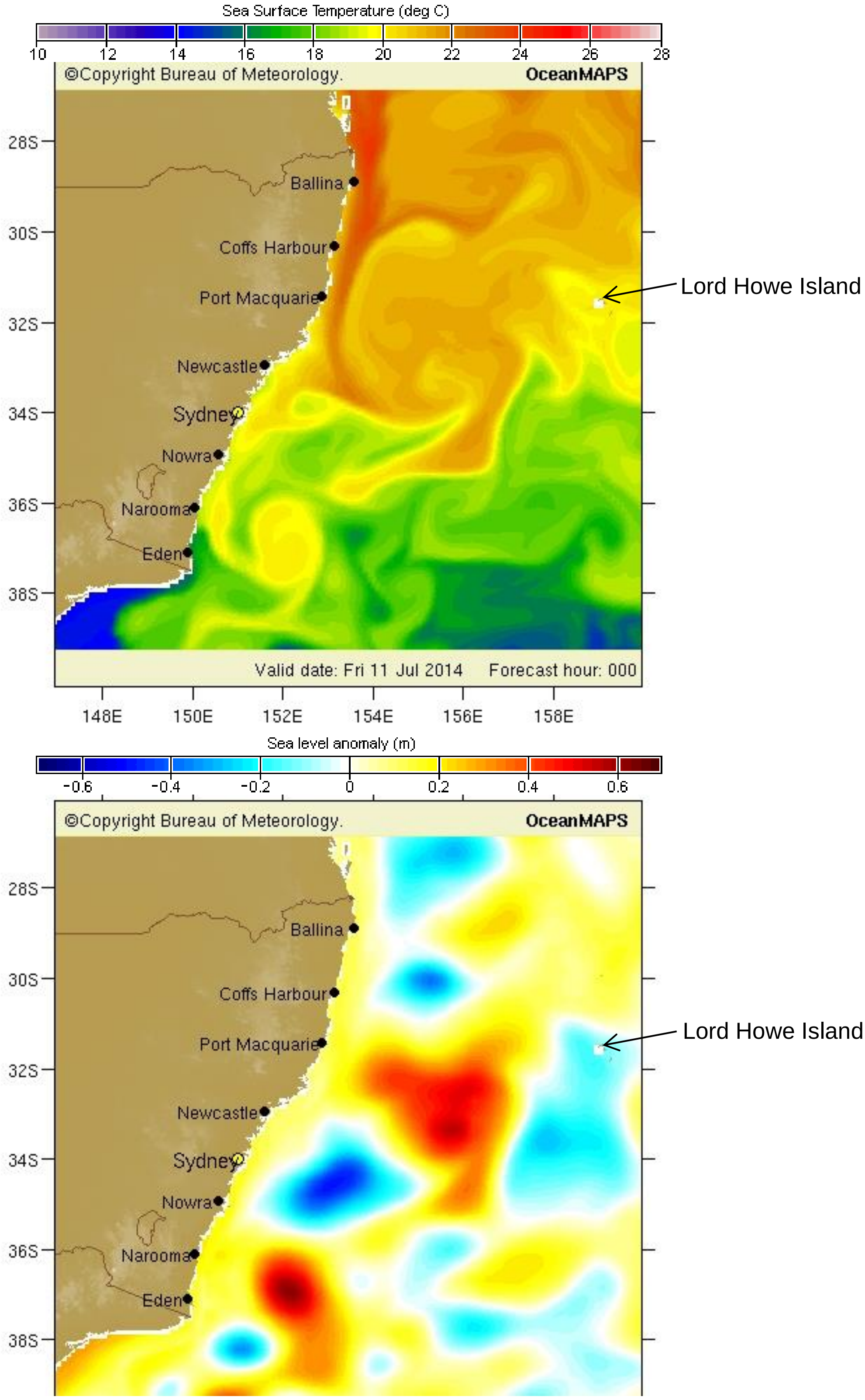
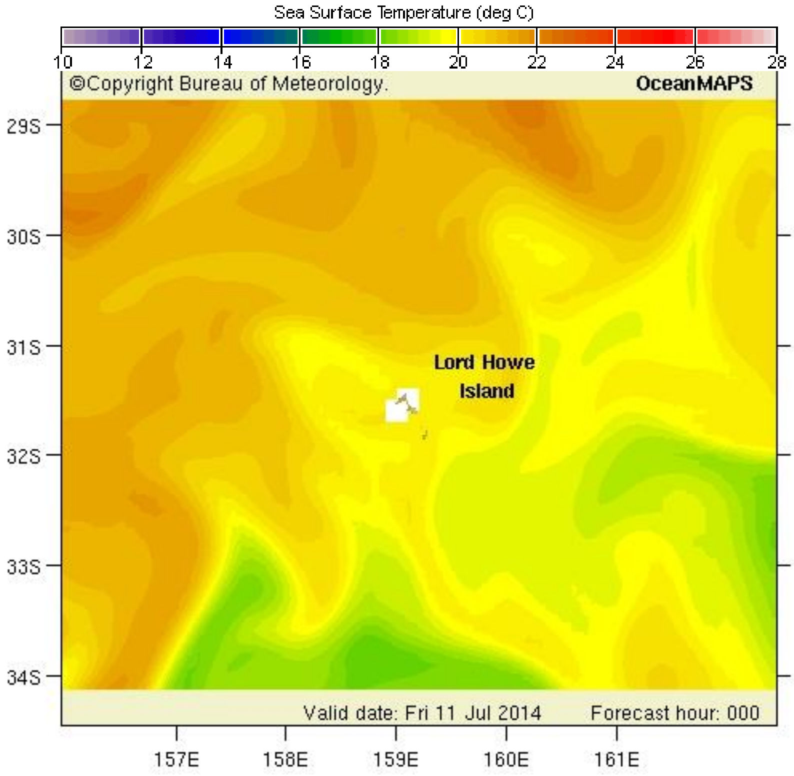


Figure 22: Example of sea surface temperature (top) and sea level anomaly results (bottom) from BLUElink for offshore of NSW



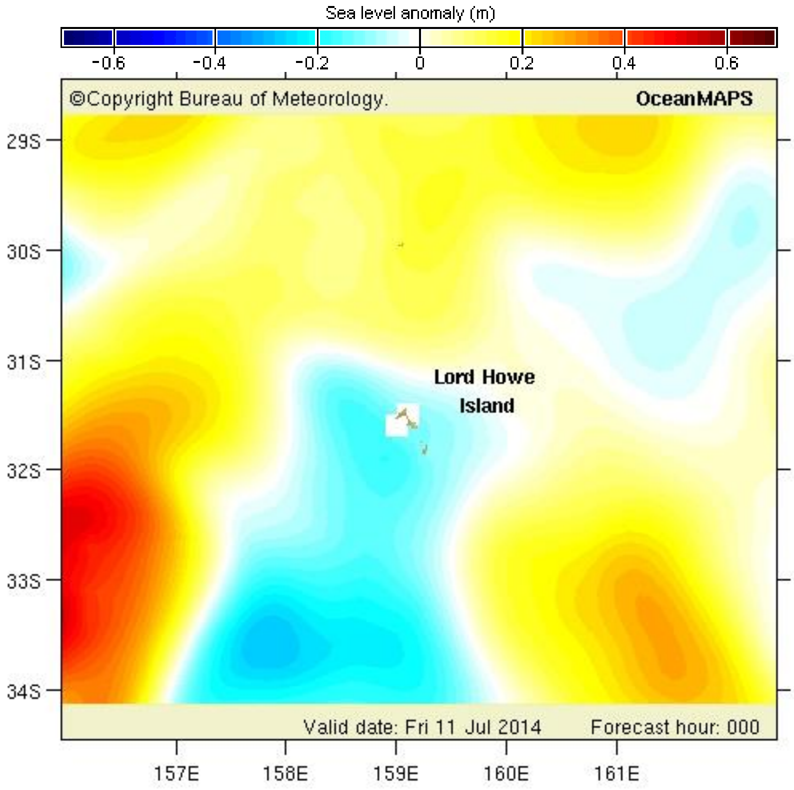


Figure 23: Example of sea surface temperature (top) and sea level anomaly results (bottom) from BLUElink for area surrounding Lord Howe Island

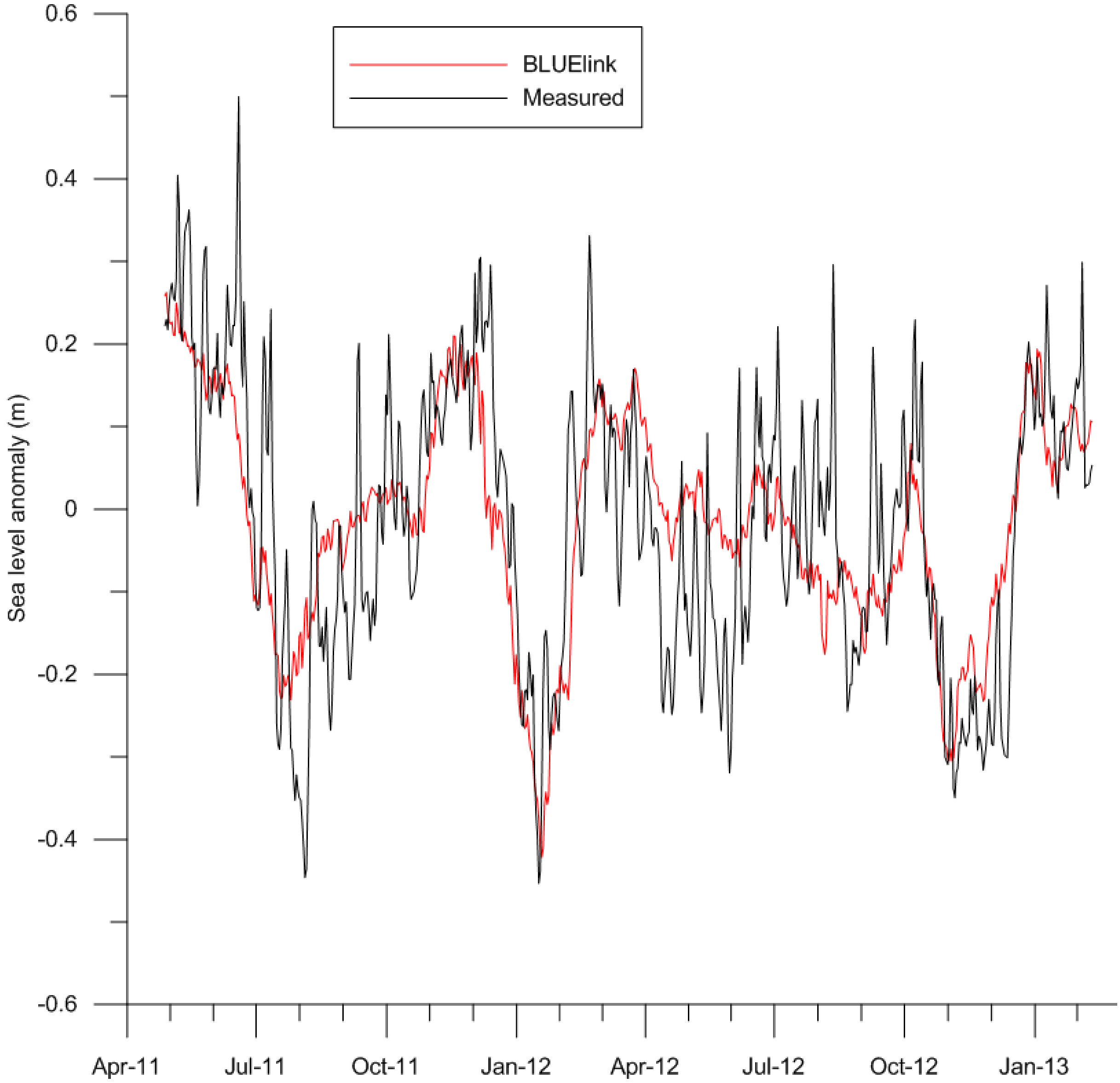


Figure 24: Comparison of measured daily average sea level anomalies in Lagoon and regional oceanographic sea level anomalies (from BLUElink) at Lord Howe Island

6.5 Wave Data

There are no known long term wave measurements offshore of or within the Lagoon at Lord Howe Island. However, there are simulated numerical hindcasts of wave conditions for most of the world's oceans that have been developed by the National Centers for Environmental Prediction in the United States (specifically the Marine Modeling and Analysis Branch of the Environmental Modeling Center) using the WAVEWATCH III® model. Details of the WAVEWATCH III® model are provided in Tolman (2009), but in essence it can be noted that the model uses winds from an atmospheric model to generate the waves.

A 31 year (from 1979 to 2009 inclusive) WAVEWATCH III® model so-called "Climate Forecast System Reanalysis Reforecast" wave hindcast at the closest model output location to Lord Howe Island[33] was downloaded from the National Centers for Environmental Prediction (2013). Details on the derivation of this time series are provided in Chawla et al (2011, 2012) and Spindler (2011). This 31 year time series had a 3 hourly time step, with output variables comprising wind speed and direction, significant wave height (H_s) and direction (θ), and peak spectral wave period (T_p). The resulting time series was analysed, with various statistics determined as listed in Table 3.

Table 3: Statistics from analysis of 31 year WAVEWATCH III® model wave hindcast at Lord Howe Island

Statistic	H_s (m)	T_p (s)
Median	2.7	11.7
Mean	2.8	11.6
Minimum	0.7	3.8
Maximum	10.4	23.4
Standard deviation	1.0	2.4
90% percentile	1.7	8.4
10% percentile	4.2	14.5
5% percentile	4.8	15.5
1% percentile	6.0	17.6

The median significant wave height (H_s) was 2.7m, substantially (80%) larger than the median H_s on the NSW mainland of about 1.5m (Shand et al, 2011). The median peak spectral wave period (T_p) at Lord Howe Island was found to be 11.7s, 23% larger than the corresponding mainland value of about 9.5s (Shand et al, 2011).

The vector average (and vector average weighted by wave height) wave direction at the Island was found to be about 228°, that is from the south-west[34]. SW waves dominated the record (with 34% of waves), and there were 29% from the SSW, 8% from the WSW and 6% from the S. That is, 63% of waves came from the SW-SSW octant, and 77% from the S-WSW quadrant.

These directional characteristics are very different to the NSW mainland, where at Sydney (for example)[35] only 0.9% of waves have been measured as coming from the SW-SSW octant, and the vector weighted wave direction is about 140° (from the SE).

In the Lord Howe Island WAVEWATCH III® data set, there were four events with H_s equal to 9m or larger (in 1982, 1986, 1988 and 2006), with the highest H_s value being 10.4m in 2006. All of these events had a T_p value of about 14s. In the 2006 event, H_s exceeded 8m for 21 hours, and 7m for 57 hours.

[33] The model had a spatial resolution of 0.5°, with the closest grid point to Lord Howe Island being at 31.5°S and 159°E. The surrounding 8 grid points were also analysed, with similar results to the adopted location closest to Lord Howe Island.
[34] Bearing relative to true north. For example, 0°, 90°, 180° and 270° represents waves from the north, east, south and west respectively.
[35] Based on analysis of directional data collected (and provided) by MHL from 1992 to 2012, with this data owned by OEH.

It can be concluded that the south-western side of Lord Howe Island is exposed to a higher wave energy wave climate than the NSW mainland, emphasising the importance of the coral reef in protecting the Lagoon and its beaches from wave action.

6.6 Meteorological Data

Based on statistics from the Bureau of Meteorology Lord Howe Island Airport station, derived from data collected between 1988 and 2014 (Bureau of Meteorology, 2014b):

- mean annual rainfall at Lord Howe Island is about 1500mm, with about 150 days of daily rainfall exceeding 1mm each year (on average);
- the wettest months (on average) are June and May, and the driest months (on average) are October and December, without an overly distinct wet and dry season;
- mean minimum temperatures vary from 13.5°C in August to 21.0°C in February (17.1°C annual average);
- mean maximum temperatures vary from 18.9°C in August to 25.7°C in February (22.1°C annual average); and
- the most dominant winds are from the south-west and east.

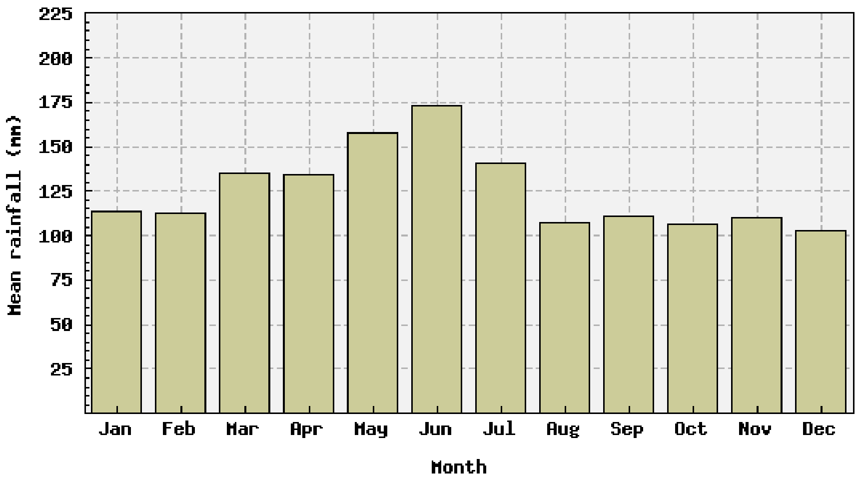


Figure 25: Mean monthly rainfall at Lord Howe Island Airport based on data from 1988 to 2014

The Bureau of Meteorology currently records meteorological data at two sites at Lord Howe Island, namely the Airport[36] (Station 200839) and at Windy Point[37] (Station 200715), with the station locations shown in Figure 26. The Airport site was established in 1988, with temperature, dew point, wind speed and direction , rainfall, mean sea level pressure and cloud amount recorded. The Windy Point site was opened in November 2003 (says 2010 in daily file), and only wind data has been recorded at this site.

[36] Denoted as "Lord Howe Island Aero" by the Bureau of Meteorology, with a station elevation of 5m.
[37] Denoted as "Lord Howe Island Windy Point" by the Bureau of Meteorology, with a station elevation of 4m.

Data was previously recorded near Jims Point[38] (Station 200440) from 1886 to 1988, recording similar variables to the current Airport site. This station has been at various locations (Les Lever, Field Office Manager, Bureau of Meteorology, Lord Howe Island, personal communication 8 October 2013), namely near Jims Point from November 1954 until when it was closed in November 1988 (Figure 27), and at various locations prior to 1954 including the first official Bureau site which was located at the Flying Boat base building (near the present Post Office located near the northern end of Lagoon Beach) from 1939 to 1954.

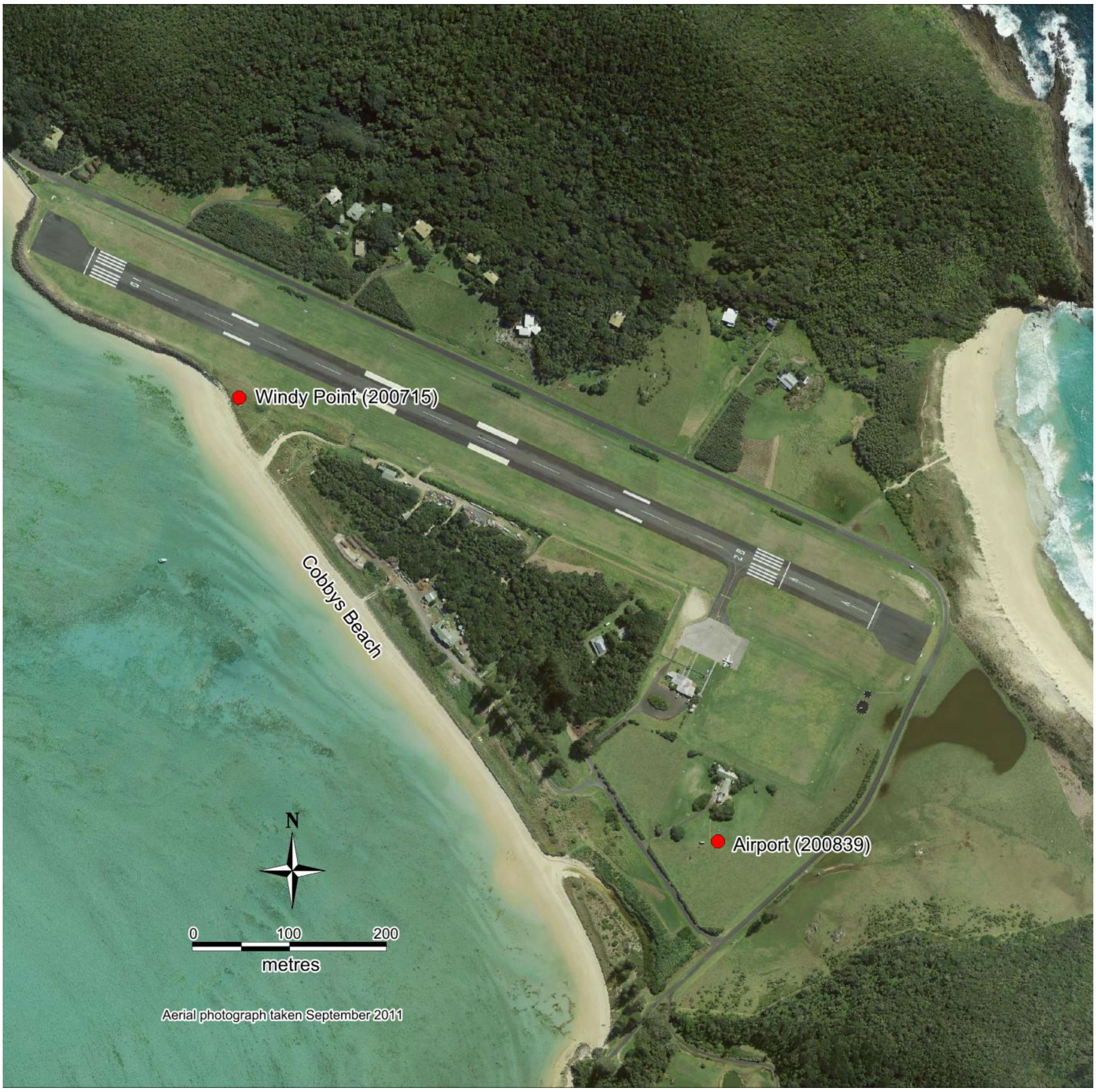


Figure 26: Location of current Bureau of Meteorology stations at Lord Howe Island

[38] Denoted as "Lord Howe Island" by the Bureau of Meteorology, with a station elevation of 46m. The latitude/longitude location of this station given by the Bureau at http://www.bom.gov.au/climate/averages/tables/cw_200440.shtml (accessed 15 April 2014) is not correct.

Figure 27: Location of Jims Point Bureau of Meteorology station (used from 1954 to 1988)

A selection of available relevant Lord Howe Island meteorological data was purchased from the Bureau of Meteorology in January 2014, namely:

- all daily and hourly records from the Airport, Windy Point and Jims Point;
- hourly data for the Airport site from 20 July 1994 to 3 January 2014, with near-continuous recording not commencing until July 2002 (about 59% data capture over the 1994 to 2014 period, and 96% data capture from July 2002 onwards), comprising rainfall, air temperature, wet bulb and dew point temperatures, relative humidity, wind speed, wind direction, speed of maximum wind gust in last 10 minutes, mean sea level pressure, station level and QNH pressure; and

- hourly data for the Windy Point site from 13 September 2004 to 3 January 2014, comprising wind speed, wind direction, and speed of maximum wind gust in last 10 minutes (with about 95% data capture over this period).

Based on analysis of the hourly data, 16 point compass wind roses for the Airport and Windy Point are provided in Figure 28 and Figure 29 respectively. It is evident that:

- most winds come from the E then ENE at both sites, then ESE (Windy Point) or SW (Airport);
- for the stronger winds (speed exceeding 40 km/hr) at the Airport, 31% come from the WSW, 24% from the E, 16% from the ENE and 12% from the W;
- for the stronger winds (speed exceeding 40 km/hr) at Windy Point, 18% come from the E, 18% from the SW, 15% from the WSW and 14% from the SSW.

Note that topographical features would affect wind directions, for example reducing the strength of winds from N to NE directions at Windy Point, and from the S to SE directions at the Airport. The southern mountains at Lord Howe Island are known to modify wind fields, creating a marked orographic effect (Martin et al, 2014).

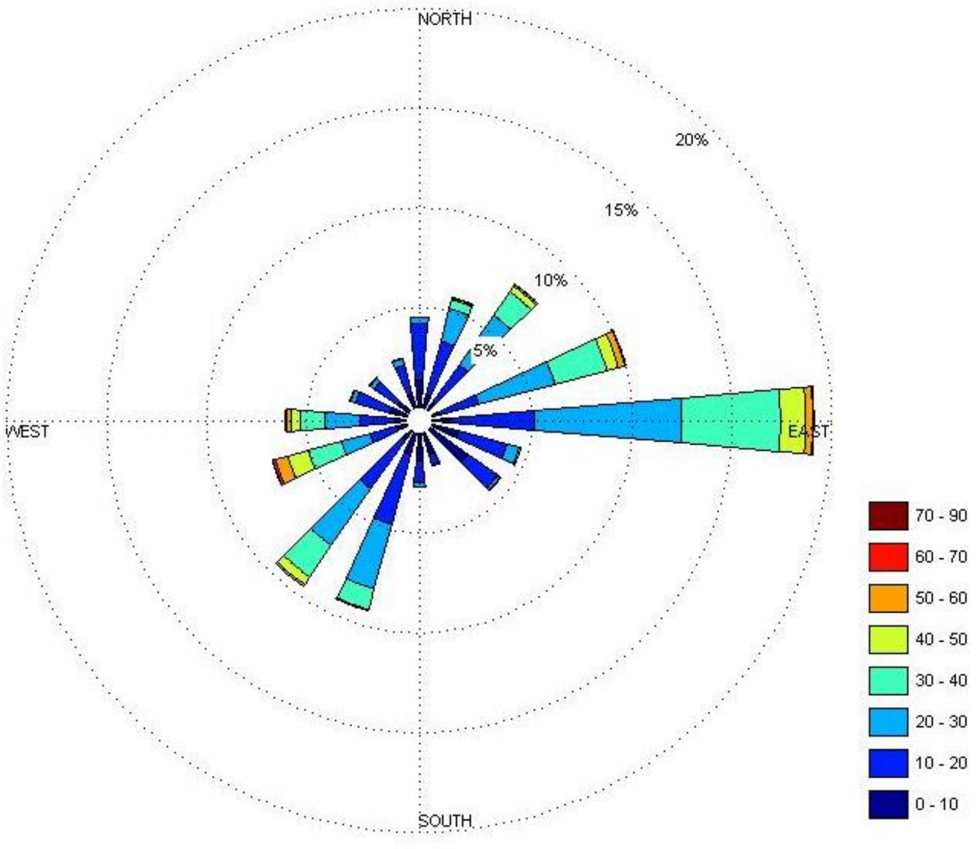


Figure 28: Wind rose for Airport site based on hourly data from 1994 to 2014

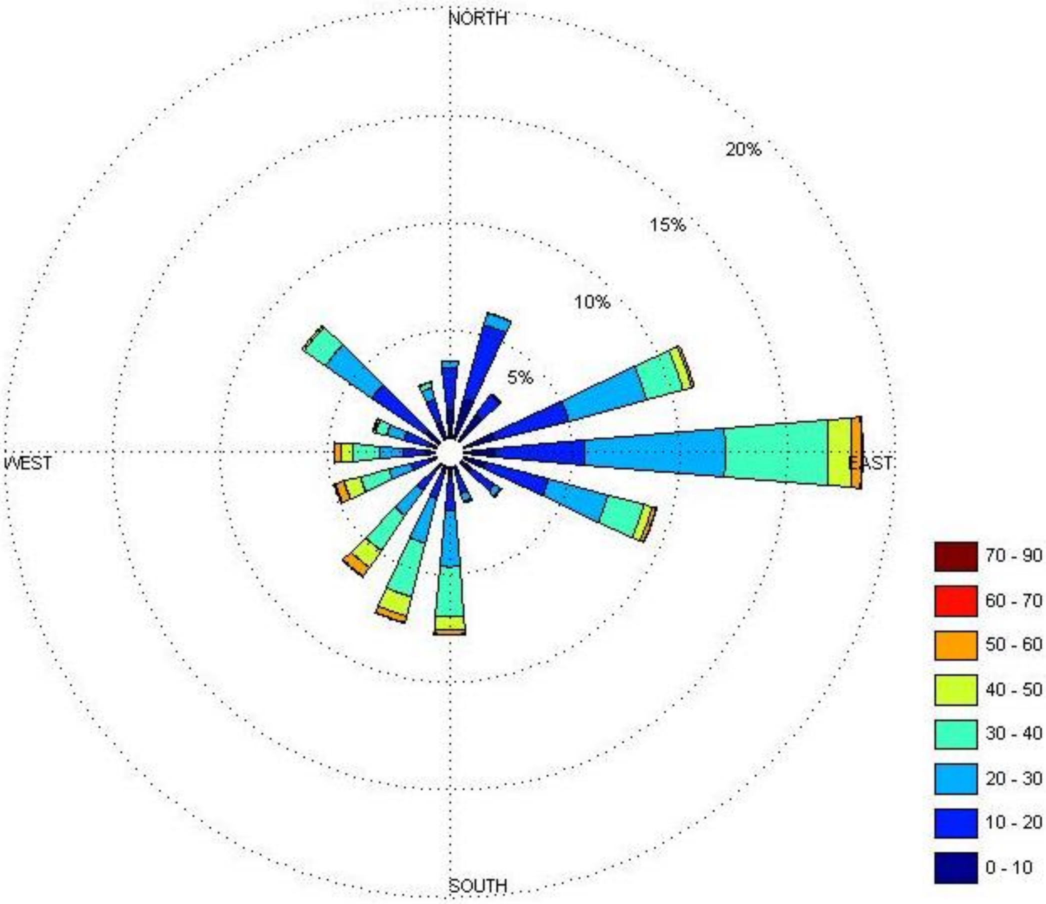


Figure 29: Wind rose for Windy Point site based on hourly data from 2004 to 2014

Analysis of the hourly Windy Point and Airport wind data over the coincident measurement period from 2004 to 2014 indicated that:

- wind speeds were (on average) about 1.2 times larger at Windy Point than the Airport; and
- wind directions were more easterly at Windy Point.

In terms of producing wind waves in the Lagoon impacting on the shoreline, the only wind directions of significance are SE through W to NW. A tabulation of the occurrence of winds from these directions (in all cases based on only the winds from SE through W to NW adding to 100%) and averaging the Windy Point and Airport data is provided in Table 4.

Table 4: Occurrence of onshore wind wave directions at Lagoon Howe Island Lagoon

Direction	Overall occurrence (%)	Occurrence for winds exceeding 40km/hour (%)
NW	11.0	1.2
WNW	6.5	1.5
W	11.7	18.6

Direction	Overall occurrence (%)	Occurrence for winds exceeding 40km/hour (%)
WSW	12.9	38.0
SW	17.3	20.7
SSW	18.2	12.4
S	11.4	7.5
SSE	3.8	0.05
SE	7.1	0.1

It is evident that although the overall winds are reasonably balanced (which would suggest no distinct net wind wave transport direction in the Lagoon), the highest winds are more from the west than south, which may cause a dominance of sediment transport to the south as littoral drift[39].

[39] Note that the Lagoon shoreline faces SW.

7. COASTAL PROCESSES

7.1 Preamble

Coastal processes in the Lagoon area at Lord Howe Island are complex. There is an interaction of waves, coral reef, reef passages, currents and elevated water levels that causes complex sediment transport patterns. There are also numerous structures that have been constructed along Lagoon Beach. These include the runway rock revetment that juts out into the Lagoon, as well as an adjacent Seabee revetment to the north and sand-filled geotextile container (bag) wall further north again. These structures are likely to be having some effect on coastal processes. That stated, erosion was occurring in the vicinity of these structures prior to their construction (including prior to construction of the runway revetment in 1974).

7.2 Water Levels

Analysis of water level data collected in the Lagoon at Lord Howe Island was discussed in Section 6.4.

7.3 Wave Climate

Analysis of wave climate numerical hindcasts representative of Lord Howe Island was discussed in Section 6.5.

Large swell waves at Lord Howe Island, which as noted in Section 6.5 generally come from the S-WSW quadrant, are likely to be generated by the following weather systems:

- Southern Ocean Lows (also known as mid-latitude cyclones, or Southern Tasman Lows when generating waves affecting the NSW mainland coast[40]). These are low pressure systems associated with fronts that move from west to east between about 40° and 60°S[41] (south of the Australian mainland), typically every 3 to 4 days. These systems would generate long period swell at Lord Howe Island, but generally not elevated water levels, due to the distance of the low (thousands of kilometres) from the island.
- East Coast Lows, which are low pressure systems that form between 20° and 40°S and generally move parallel to the NSW coast, often intensifying rapidly (Shand et al, 2011). These can generate both large waves and elevated water levels due to storm surge.
- Southern Secondary Lows, which are storms that form as a cut off low in the wake of a cold front in a mid-latitude westerly circulation (Shand et al, 2011)[42].
- Ex Tropical Cyclones, where the cyclones generally form north of 20°S. These can lead to particularly large waves and elevated water levels at Lord Howe Island if the cyclone tracks close to the Island. Tropical Cyclones typically form in the warmer months (November to April) only.

[40] For example, Shand et al (2011) used the "Southern Tasman Lows" term. Southern Ocean Lows are the dominate source of swell waves that affect Indonesia, Western Australia, South Australia and Victoria. Once Southern Ocean Lows have moved far enough east to generate waves that affect the NSW mainland, the term "Southern Tasman Lows" can be used.

[41] Covering the "roaring forties", "furious fifties" and "screaming sixties", a region characterised by westerly gales.

[42] Shand et al (2011) classified East Coast Lows and Southern Secondary Lows as "East Coast Cyclones", and also included Inland Troughs and Tropical Cyclones in this category.

With reference to PWD (1986) and Callaghan and Helman (2008), the four largest events in the 1979 to 2009 WAVEWATCH III® analysis (Section 6.5) were East Coast Lows (July 1986 and June 2006), and Southern Secondary Lows (July 1982[43] and August 1988). However, note that WAVEWATCH III® does not resolve tropical cyclones well, and there is evidence that more tropical cyclones tracked towards Lord Howe Island in the 1950s to 1970s than in recent decades.

7.4 Ocean Currents

The East Australian Current (EAC) carries warm low salinity Coral Sea water southward into the cooler more saline Tasman Sea. The northern limit of the EAC is usually defined as latitude 18°S whilst its southern boundary, usually at latitude 32°S, is quite variable and can extend as far south as 42°S (NCCOE, 2012).

The EAC is present at all times of the year but is generally strongest between December and April. Its surface speed is usually between 0.5 and 1.0 m/s and its effect can be felt at depth. Seaward of the continental shelf the current speed at a depth of 250m is approximately half that at the surface. The maximum width of the EAC is about 150km (NCCOE, 2012).

The landward edge of the current frequently encroaches onto the shelf with an effect on coastal processes such as the movement of seabed sediment. The southerly flow often separates from the coast between 29°S and 32°S, heading east across the Tasman Sea. At the point of separation the current repeatedly forms loops that break off as large eddies that can sometimes interact with coastal waters similarly to the EAC itself (NCCOE, 2012). With Lord Howe Island at 31.5°S, the warmer EAC waters thus episodically reach the Island.

Further information on the EAC is given by Boland and Church (1981).

7.5 Nearshore Wave Climate in Relation to Reef and Lagoon Features

In Figure 30, the vector average swell wave direction of 228°, that is from the south-west, is depicted at various locations. Surrounding Blackburn Island, there is a gap in the reef about 510m wide. At Location 1 (north of Blackburn Island), there would therefore be relatively higher wave energy entering the Lagoon, although the wave energy reaching Lagoon Beach would be reduced and spread (through diffraction) due to the relatively narrow gap between the reef and island of about 100m[44]. This may be a factor in the area near Location A at Lagoon Beach in Figure 30 not showing significant progradation, unlike surrounding areas[45].

At Location 2 (south of Blackburn Island), there would again be relatively higher wave energy entering the Lagoon. Although diffraction may again reduce wave energy, and the deeper areas in the Lagoon would also transform wave height and direction through refraction, it would be expected that Location B along Lagoon Beach in Figure 30 would be subject to relatively higher wave energy. The extent of this region is due both to:

[43] Initially an Anti-cyclone Intensification.
[44] Gap distance measured perpendicular to the dominant wave direction.
[45] It is understood that a bulldozer occasionally clears the access track from the Aquatic Club to the beach to assist vessel access, which may also have relatively reduced sand volumes in this area.

- the direction windows that would penetrate the gap south of Blackburn Island (SW, WSW, W and WNW waves[46]); and
- the relatively low reef crest levels at Locations 3 and 4 (from 0.3m to 0.7m AHD).x

Location B corresponds to the area receding at the southern end of Lagoon Beach.

At Location 5 in Figure 30 there is also a slight gap in the reef crests and relatively lower reef crest levels, which may be contributing to the recession immediately south of the runway revetment. That stated, there are other factors affecting recession of this area as discussed in Section 7.8.

It is recognised that any opposing current in the reef passages (such as surrounding Blackburn Island) may limit wave energy entering the Lagoon, but the evidence is there that the areas potentially most exposed to wave energy are those that are receding, recognising that there are also other factors affecting recession.

[46] 34% of waves come from the SW, 8% from the WSW, 4% from the W and 3% from the WNW.

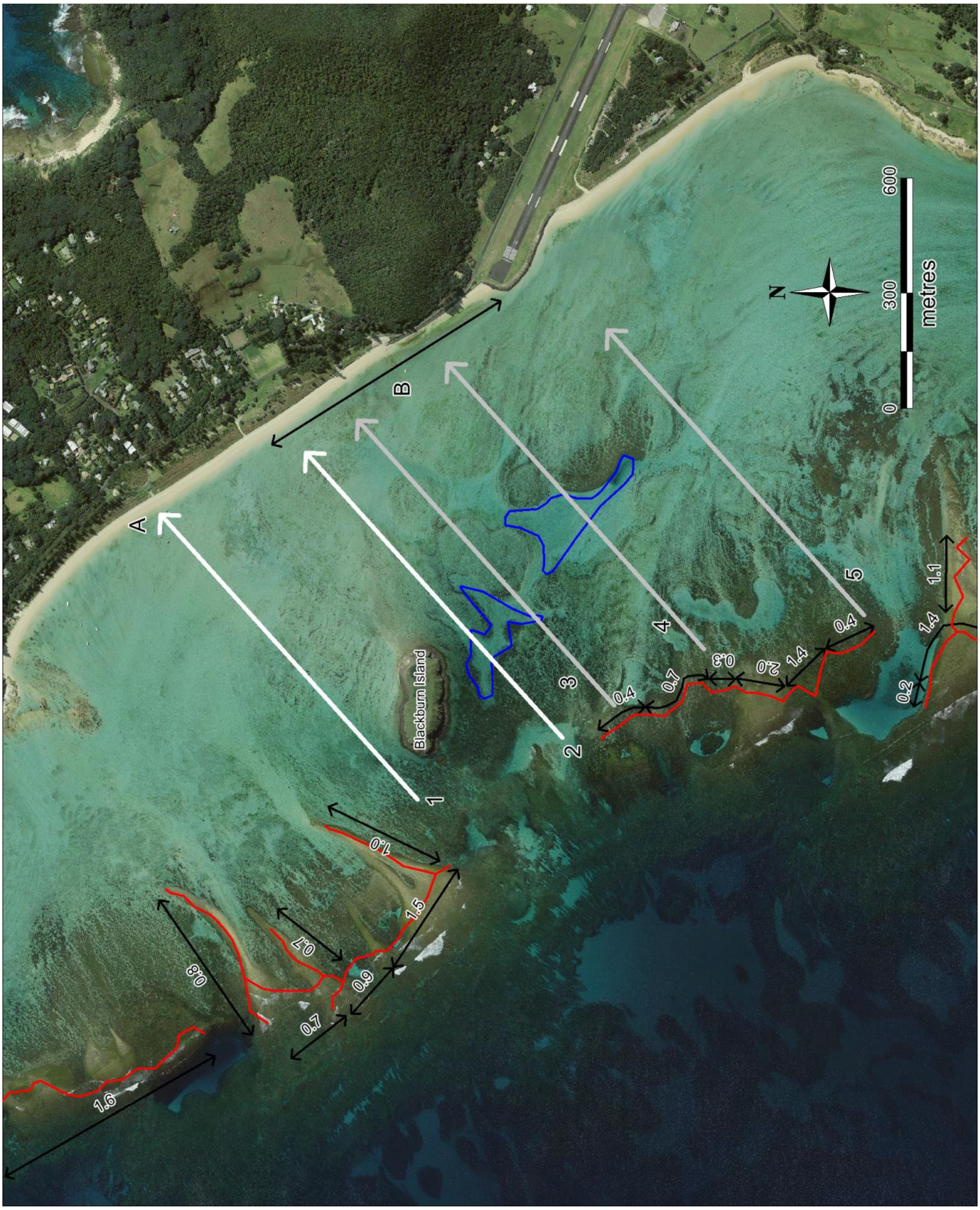


Figure 30: Potential higher wave energy areas (A and B) impacting on Lagoon Beach and Cobbys Beach, with vector average offshore wave direction vectors shown (note that wave transformation in the Lagoon could alter these directions)

7.6 Effects of Structures and Works on Beach

7.6.1 Runway Revetment

If there are significant longshore sediment transport processes along Lagoon Beach and Cobbys Beach, then it would be reasonable to expect that the runway revetment (if it extended a sufficient distance into the Lagoon to interrupt longshore sediment transport) would act like a groyne and cause buildup of sediment on the updrift side and loss of sediment on the downdrift side. There is not conclusive evidence that there has been a significant groyne effect at the runway, and the relatively benign wave conditions along Lagoon Beach for most of the time are consistent with that observation. It is also possible that any modest longshore sediment transport bypasses the runway, as the runway protrusion is relatively insignificant.

It should be noted that literature prepared in relation to managing erosion in the Windy Point area[47] consistently had statements indicating an expectation that the dominant longshore movement of sand along Lagoon Beach was from north to south, and thus that the runway construction had caused accelerated erosion south of the runway. If this was the case, the area north of the runway revetment would (if anything) have benefited from sand accretion due to the runway construction.

That stated, a conceptual model of sediment transport prepared by Patterson Britton & Partners (1991)[48] as presented in Manidis Roberts Consultants (1993) indicated that there was an expectation that the runway was a transition zone for the direction of sediment transport, with sand moving to the north from north of the runway and sand moving to the south from south of the runway.

Manly Hydraulics Laboratory (1968) noted that changes in beach conditions from construction of the airstrip could be studied in a model to minimise any objectionable features. No such studies are known to have been undertaken.

A structure such as the runway located in areas of wave impact and sediment transport would be expected to have some localised “end effects”, where there can be additional erosion (beyond what would have occurred if the structure had not been there) adjacent to the structure[49]. Consideration of the magnitude of these end effects (in relation to the adjacent and more substantial Seabee revetment) is made in Section 7.6.2.

There is also the possibility that the runway construction (in combination with the Seabee revetment) could be considered to be a “hard point” or “artificial headland” around which Lagoon Beach is realigning. SMEC (2012) noted this process in relation to “a shoreline evolution model which can predict the crenulated bay response of a shoreline downdrift (in a sediment transport sense) of a fixed headland”, although the prediction they developed in Figure 17 of their report (which indicated that the southern end of Lagoon Beach was trending to realign substantially landward, north of the bag wall) was based on limited data. Windy Point may have historically been such a hard point as it jutted out into Lagoon Beach prior to the runway construction.

However, there needs to be care in attributing erosion problems in the Windy Point area to construction of the runway. Erosion of this area was occurring prior to the runway construction based

[47] Including Public Works Department (1989) and Manidis Roberts Consultants (1993).
[48] Reference uncertain. Original document has not been sighted and it was not included in the references of the citation source.
[49] These end effects are sometimes at least partially attributed to the fact that a hard structure “locks up” sand from being available to meet storm demand.

on discussions with long term residents of Lord Howe Island. Manidis Roberts Consultants (1993) also stated that the road at Windy Point had been undermined and rebuilt about six times in the past, prior to the runway construction.

7.6.2 Seabee Revetment

Public Works Department (1989) noted that construction of a sloping revetment (of which a Seabee revetment is an example) would create flanking problems, that is accelerating recession of adjacent unprotected sections of beach. However, they considered that a 280m length of protective works north of the runway revetment (similar in length to the Seabee revetment that was constructed) would not be likely to result in increased erosion hazard to existing backbeach development at the ends of the works that was present at that time[50].

Department of Environment, Climate Change and Water [DECCW] (2010a) has released "Draft Guidelines for Assessing the Impacts of Seawalls". For a structure such as the Seabee revetment, which can be considered to be located between the intertidal zone and the 1 year ARI wave runup level, it was suggested that the alongshore extent of additional erosion adjacent to the wall was the lesser of 70% of the length of the wall or 500m. For the 300m long Seabee revetment, using this methodology, the additional erosion extent would be predicted to be 210m.

Note that the DECCW (2010a) methodology is simplistic and does not take into account the direction and magnitude of longshore sediment transport, or magnitude of storm erosion demand, for example. Furthermore, beach profile changes over time would indicate that the area south of the Seabee revetment and runway revetment has been accreting from beyond 80m from these structures.

7.6.3 Beach Scraping

It is understood that it has been an historical practice to push sand up to the eroding dune from around the low tide area as a form of beach scraping at the southern end of Lagoon Beach, and at Windy Point prior to the construction of the Seabee revetment.

The Board had a NSW Marine Parks Permit for "beach scraping to protect the foredune, beach access and the Pinetrees Boatshed from further coastal erosion" (covering the area approximately 40m to either side of the Boatshed) that was applied for in April 2011, but has now lapsed.

More recently (in the last year or so), it is understood that the methodology for beach scraping may have changed to sourcing sand from about 50m to 200m north of Pinetrees boatshed (again at the low tide level) and transporting the sand alongshore (south) along the beach before pushing the sand upwards and forming a mound adjacent to the erosion escarpment. An example of a mound of sand formed seaward of Pinetrees boatshed and caused by beach scraping carried out in this manner is depicted in Figure 31. Such works were undertaken three times in 2012.

[50] Which would have included Lagoon Road (although note that Pinetrees boatshed was not present at this time).

Figure 31: Sand from beach scraping pushed against erosion escarpment at Pinetrees boatshed, 28 August 2012

Carley (2010) has defined beach scraping as “the movement of sand from the intertidal zone to the dune or upper beach by mechanical means”. The term “cross-shore beach scraping” has been used herein to describe the mechanical cross-shore transport of sand from the lower to the upper profile. To distinguish between this, and alongshore mechanical sand transport prior to cross-shore scraping, the latter has been denoted as “longshore and cross-shore beach scraping” herein (see Figure 32 for illustration of concepts). However, note that it is uncertain how much “cross-shore beach scraping” versus “longshore and cross-shore beach scraping” has been undertaken, as the final results of the works appear similar.

Given the relatively sheltered nature of Lagoon Beach with low height waves for most of the time, the process of beach recovery after storms could be relatively slow, reducing the effectiveness of cross-shore beach scraping. Indeed, Carley (2010) noted that where beach scraping rates exceed natural recovery rates, this may cause over-steepening of beaches and additional erosion. There could be this concern for cross-shore beach scraping at Lagoon Beach. It is thus recommended that cross-shore beach scraping is discontinued at Lagoon Beach.

The same concerns could be raised with regard to “longshore and cross-shore beach scraping”, although depending on the direction of longshore sand transport these works may be beneficial in reducing erosion in the Pinetrees boatshed area[51].

It is recommended that the practice of mounding sand in a localised bulge immediately adjacent to the erosion escarpment is discontinued, as it is likely to contribute to losses of this material from the sandy beach into dunal areas from wind action. It is likely to be more effective to spread the material over a wider cross-shore area.

It is also recommended that the sand source for longshore scraping is moved further north (north of the access track opposite the Board’s Administration office), and that excess sand removed from the slipway area at the northern end of Lagoon Beach is also utilised as a sand source. Based on historical accretion rates at the northern end of the beach, it is likely that at least 500m^3/year of sand could be sourced from the northern end of the beach and placed at the southern end, without any long term impact on coastal processes.

[51] If longshore transport is to the north, then removing sand from north of the boatshed and transporting it and placing it back near the boatshed is likely to reduce erosion in its vicinity. Conversely, if longshore transport is to the south, this operation would create a hole (sink) for sand north of the boatshed that would need to fill, thus causing downdrift erosion to the south due to reduced longshore supply of sand (until the filling of the hole occurred and longshore transport rates were fully re-established). Given that the first scenario is considered to be most likely, removing sand from north of Pinetrees boatshed and transporting it and placing it back near the boatshed is likely to reduce coastline hazards at the boatshed.

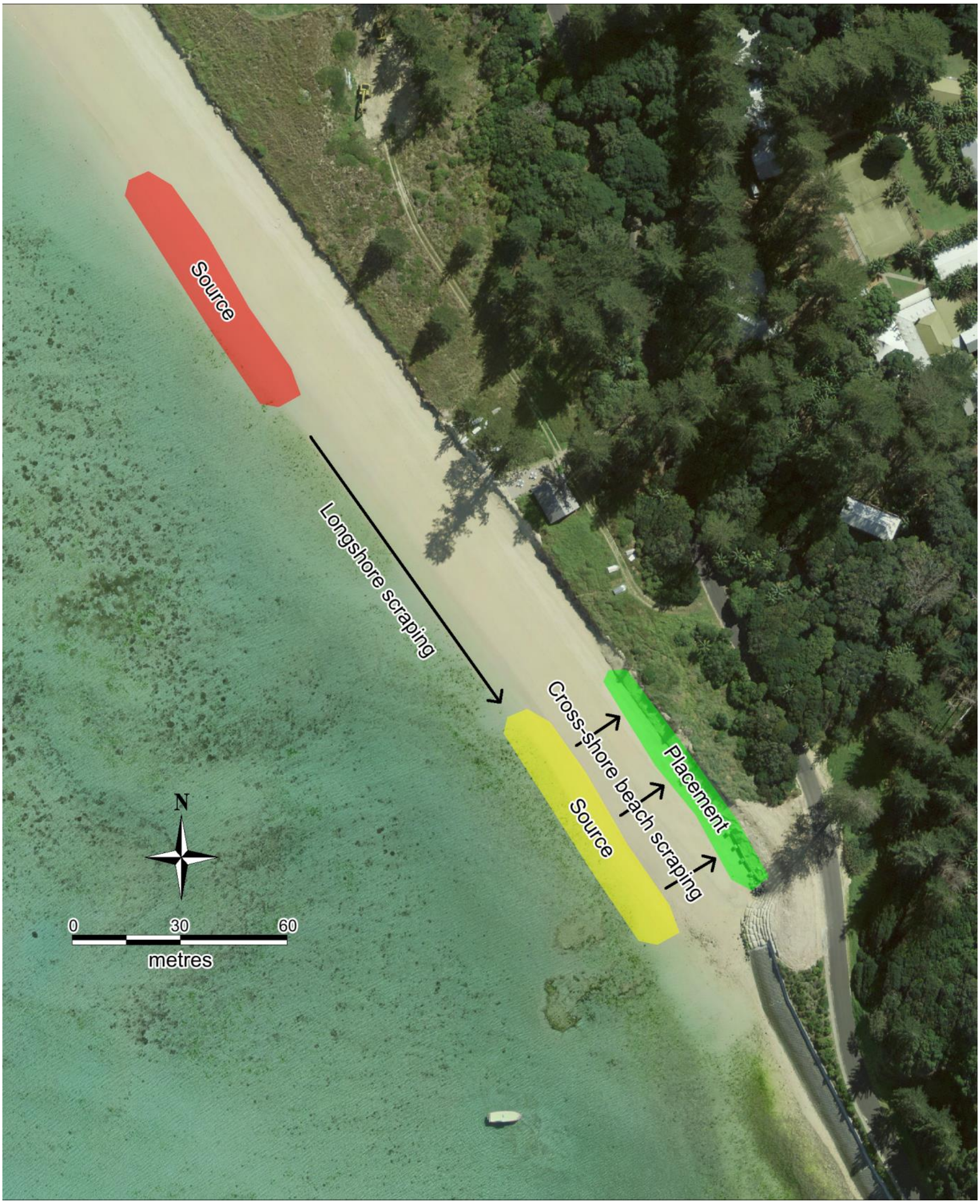


Figure 32: Difference between "cross-shore beach scraping" and "longshore scraping" as illustrated in the vicinity of Pinetrees boatshed (if longshore scraping was undertaken it would provide source for cross-shore beach scraping)

7.7 Sediment Transport

7.7.1 Onshore/Offshore Sediment Transport

Onshore/offshore (also known as cross-shore) sand movement is caused by natural variations in wave climate and water level. The offshore movement of sand is usually referred to as storm erosion. This onshore/offshore movement of sand results in short term fluctuations in the volume and width of the beach profile.

On the NSW mainland coast, beach sand typically moves offshore to form bars during storms (when relatively large and steep waves occur). This process typically occurs over a period of hours to days. When extended periods of calmer wave conditions occur (characterised by relatively long period and low height swell, that is less steep waves), the material held in these bars migrates onshore to rebuild the beach. Depending on the magnitude of the preceding storm, this beach building process can occur over a time scale of days to years.

Along Lagoon Beach and Cobbys Beach at Lord Howe Island, there is less certainty as to the mechanisms of onshore/offshore sediment transport. Storm erosion certainly occurs at Lord Howe Island, but it is uncertain if significant offshore bars form, or sand is smeared more widely over the Lagoon, given the relatively flat Lagoon bed. Also, there is uncertainty as to the effectiveness of long period and low height swell in rebuilding these beaches after storms. This is because wave heights within the Lagoon are relatively low during calmer conditions (due to the offshore reef), and may not have sufficient energy to mobile sediment. Indeed, it is possible that it is the large and steep storm waves (rather than calmer conditions) that mobilise sediment off the reef and Lagoon bed and move it onshore (with such storms leading to upper beach erosion but onshore sediment transport over the wider Lagoon bed).

The amount of sand which can be removed from a beach during a storm event (or series of closely spaced storms) and transported offshore is referred to as the “storm demand”. On the NSW mainland, this quantity is generally measured above 0m AHD (approximately mean sea level on the NSW mainland, but 1.2m below mean sea level in the Lagoon at Lord Howe Island), and is usually expressed as a volume per metre length of beach (m^3/m). Knowledge of the storm demand for a beach allows estimation of the amount of material required to be held in reserve for a storm in order to protect a given asset landward of the beach. It also allows estimation of the degree to which a beach would be eroded or cut back in a storm for a given pre-storm beach profile.

7.7.2 Adopted Long Term Recession Rate Due to Net Sediment Loss

Based on review of photogrammetric data (**Appendix B**), the long term recession due to net sediment loss rates listed in Table 5 were adopted:

Table 5: Adopted long term recession due to net sediment loss rates

Profiles	Rate (m/year)
1-17	Nil
18-21	0.1
22-34	0.4
35-37	0.5

Profiles	Rate (m/year)
38-52	Nil

7.8 Conceptual Model of Sediment Transport Mechanisms

The rates of beach change outlined in Section 6.1 do not definitively reveal where the gains and losses in each compartment have come from (that is from offshore or alongshore). However, there appears to be a general pattern of progradation at these beaches, which is considered to be most likely from an ongoing onshore transport of sediment from the relatively shallow Lagoon at the northern end of Lagoon Beach and from offshore of Cobbys Beach[52]. There may also be some swell wave driven alongshore transport of sand near the waterline, expected to be to the north along Lagoon Beach on average[53].

However, given that 8,000m^3 of sand (sourced from Blinky Beach) was placed along the position of the current Seabee revetment in 1991, the rates of change measured in Section 6.1 may be an overestimate of the natural rates of progradation (in the order of 20%)[54]. That is, the prograding areas of Lagoon Beach and Cobbys Beach are still likely to be naturally prograding, but the measured progradation is likely to have been influenced by the previous nourishment in 1991.

Superimposed on this general progradation are isolated losses adjacent to the runway revetment and Seabee revetment, which may be considered as related to :

- the higher wave energy impinging on this area (Section 7.5) causing relatively higher offshore sand transport in storms;
- "end effects" and additional seaward erosion associated with structures interfering with natural coastal processes;
- the deeper areas in the vicinity of Comets Hole (Section 7.5) acting as a sink for sediment (reducing onshore supply of sediment and generally capturing sand transport in this area); and
- general circulation patterns in the Lagoon.

Although erosion did occur at the southern end of Lagoon Beach prior to the structures being built (erosion is a natural process, that is a natural response to large waves and elevated water levels), it appears that the structures may have enhanced the loss of sediment from these areas in storms, and/or inhibited the recovery of sediment volumes after storms (perhaps by additional turbulence etc causing sediment to be moved further offshore in storms). Structure effects are recognised in the coastal engineering literature due to turbulence and oblique wave reflection. That stated, additional analysis (such as sediment tracing) would be required to more definitively ascertain the relative contribution of natural and anthropogenic processes causing erosion in the vicinity of these structures.

Lord Howe Island residents (such as Clive Wilson and Anthony Riddle) have noted that water circulation patterns in the Lagoon are towards the south in the vicinity of Cobbys Beach. Anthony Riddle has also noted that there is a northwards flow offshore of Lagoon Beach. From a coastal

[52] It is considered to be unlikely that there is much transport of sand around the Signal Point area at the northern end of Lagoon Beach. There may be some infeed of sand from the south at Cobbys Beach, but this is uncertain given the reported water circulation patterns to the south in this area (see further discussion below).

[53] Local wind waves may also drive alongshore sediment transport, but these have not yet been considered.

[54] The observed gains in volume at the northern end of Lagoon Beach and southern end of Cobbys Beach between 1984 and 2001 were about 19,700m^3 and 21,500m^3 respectively. Thus 8,000m^3 of nourishment sand could have contributed up to about 20% of this volume gain.

processes perspective, such flows are plausible as waves pump up lagoon water levels, which leads to strong flows out of the reef passages. The Seabee revetment location represents the midpoint between North Passage and Erscotts Passage and may be the point where circulations shift in direction from northerly to southerly. Note however that it is uncertain if these circulation currents are fast enough to transport sand-sized sediment, particularly near the shoreline[55].

A preliminary conceptual model of sediment transport processes that is an attempt to document the observed beach changes and is consistent with observed circulation patterns is depicted in Figure 33. The size of arrows indicates the magnitude of sediment transport in the direction shown. Although offshore transport (due to erosion in storms) can occur along the entire length of Lagoon Beach and Cobbys Beach as shown, it is considered that the areas near the Seabee revetment and runway revetment may have additional offshore erosion which combined with reduced offshore supply of sediment may be causing the net recession in this area (in combination with some longshore transport of sediment).

It is also likely that beach recovery after storms is relatively slow at Lagoon Beach, and the natural rebuilding of eroded areas after storms may take months or years, or possibly not ever be completely achieved (particularly if onshore sediment supply is diminished), leading to long term recession.

A sediment tracing study (Section 12.2.7) would provide valuable insight into a more refined conceptual model of sediment transport mechanisms.

[55] As noted above, it would also be possible to get alongshore movement of sand due to wave effects, where waves break at an angle to the shoreline.

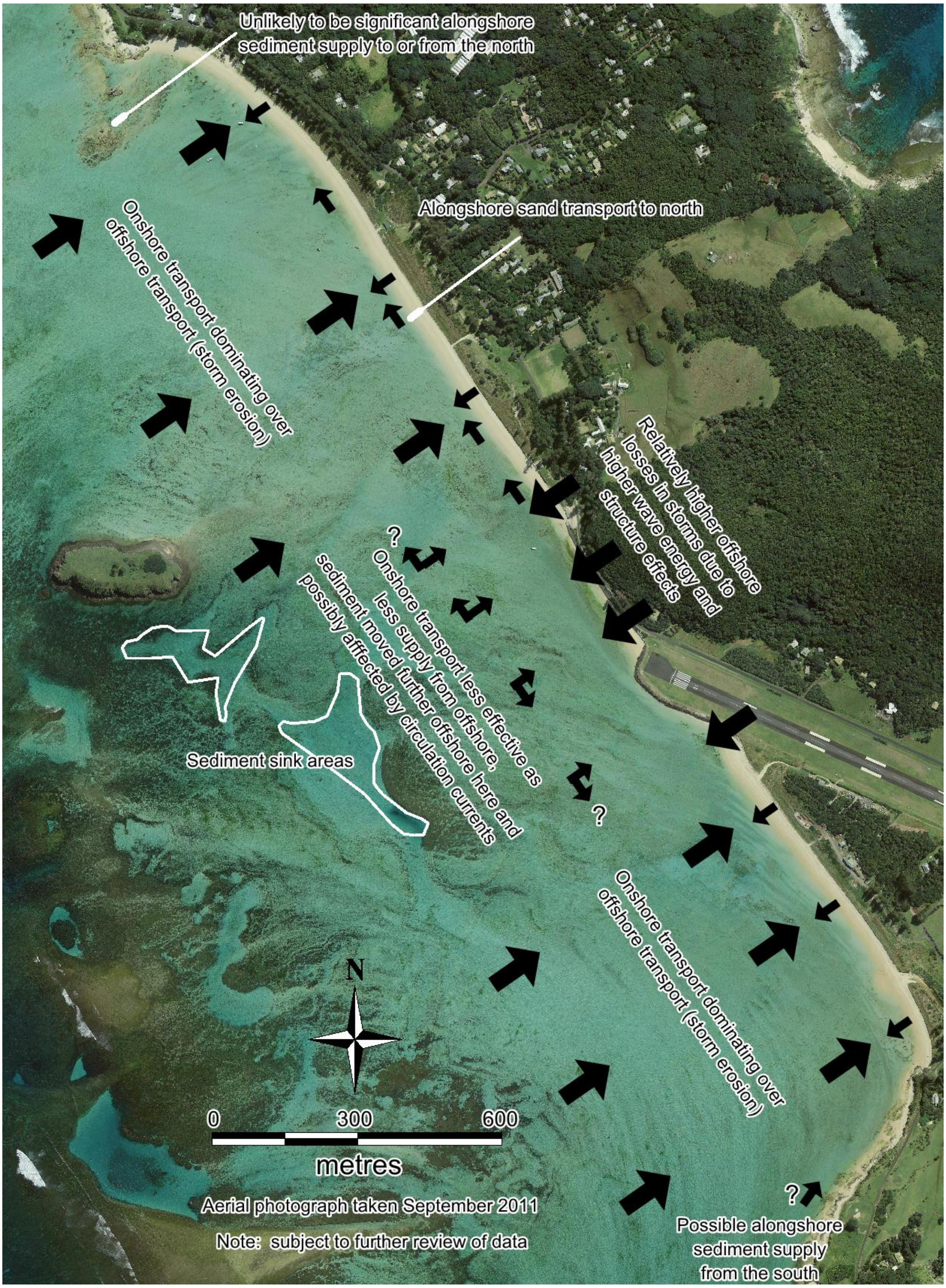


Figure 33: Preliminary conceptual model of sediment transport processes in Lagoon and at Lagoon Beach and Cobbys Beach

7.9 Climate Change

7.9.1 Sea Level Rise

The possibility of global climate change accelerated by increasing concentrations of greenhouse gases, the so-called Greenhouse Effect, is widely accepted by the scientific and engineering communities. This is projected to cause globally averaged surface air temperatures and sea levels to rise.

The Board directed that the sea level rise benchmarks in the former *NSW Sea Level Rise Policy Statement* (DECCW, 2009a, b), which is no longer NSW Government policy, be used to assess future coastline hazards herein. These benchmarks are an increase in mean sea level (relative to 1990) of 0.4m at 2050 and 0.9m at 2100.

The latest (Fifth Assessment) Intergovernmental Panel on Climate Change (IPCC) projections of future sea level rise were released in 2013 (IPCC, 2013a, b). It is recommended that there is consideration of applying these IPCC projections in a probabilistic risk framework, rather than relying on the former *NSW Sea Level Rise Policy Statement* benchmarks, to estimate future coastline hazards. That stated, these former benchmarks provide reasonable conservative allowances for planning purposes.

The actual sea level rise that would occur in the future is uncertain due to approximations in the modelling used to develop the projections, plus the fact that the modelling results are dependent on the greenhouse gas emission scenario adopted (which varies depending on a variety of economic and political influences that cannot be precisely foretold). That stated, it is likely that the sea level rise benchmarks adopted here would be towards the upper end of sea level rise that would be realised.

As discussed in Section 8.3.3, it is generally expected that recession of the open coast will occur under conditions of accelerated sea level rise.

7.9.2 Other Climatic Change Considerations

There are a number of other climate change effects (besides sea level rise) that could potentially impact on Lord Howe Island, namely:

- changes to community composition and structure of coral reef systems driven by increasing sea surface temperatures and ocean acidification[56];
- increased frequency and intensity of extreme rainfall[56] leading to increases in terrestrial runoff and nutrient and sediment loads being input into the Lagoon, impacting on reef health;
- an increase in the frequency and intensity of coastal storm (extreme wave) events, that could lead to increased erosion of beaches;
- changes in the angle of approach of the predominant wave climate, that could cause realignment of the shoreline and resulting recession in some areas and progradation in others;
- alterations to oceanographic circulation patterns, that could lead to localised variations in mean sea level over periods of months, which influences the wave energy that can penetrate into the Lagoon; and
- the reef crest level not keeping up with sea level rise, leading to increasing wave energy penetrating into the Lagoon.

[56] Identified as a key regional risk to Australasia in the IPCC Fifth Assessment (Reisinger and Kitching, 2013).

Ocean acidification is associated with increased carbon dioxide (CO_2) emissions. Coral reefs are particularly vulnerable because the increased CO_2 concentration in seawater, which combines with water to form carbonic acid, can make it hard for corals to grow. Models, observations and laboratory studies consistently indicate that as the ocean becomes more acidic, coral cover and diversity will decrease (Wendel, 2014).

The increased CO_2 concentration in seawater causing a lowering of pH (acidification) is not the only impact on reefs, it is also the reducing concentration of carbonate ions (CO_3^{2-}) that calcifying organisms need to build and cement coral reef (Howard et al, 2012; Shamberger et al, 2014). This reducing concentration of carbonate ions is also referred to as lowering the saturation state of carbonate mineral, and calcium carbonate precipitation at a decreased saturation state requires higher energetic demands from shell-making organisms (Howard et al, 2012).

Anthony and Marshall (2012) also noted that the increased CO_2 concentration in seawater may lead to increased fragility of coral skeletons and accelerated rates of reef bioerosion, increasing the susceptibility of reefs to storm damage. They considered that ocean acidification would reduce reef calcification, driving a shift from net reef accretion to net erosion of reef structure.

At Lord Howe Island, Anderson et al (2012) noted that growth rates of corals may currently be limited by relative cooler winter ocean temperatures, leading to negligible coral growth in winter months. Therefore, increasing ocean temperatures due to climate change may extend the growing period, enhancing overall growth rates. Ridgway (2007) and Ridgway and Hill (2012) identified that the East Australian Current had penetrated about 350km further south over the last 60 years, contributing to ocean warming in more southerly waters.

However, Anderson et al (2012) noted that the positive effects of increasing ocean temperature may be offset by declines in carbonate (aragonite) saturation. They stated that aragonite saturation declines with increasing latitude and climate-induced ocean acidification may further reduce the capacity for growth of calcifying organisms at the latitudinal limits of reef growth at Lord Howe Island[57].

It is unclear how the amplitude or frequency of the El Niño/Southern Oscillation (ENSO) phenomenon may change over the next 100 or so years (Holbrook et al, 2012). This is of interest as it drives changes in sea level, ocean temperature, the East Australian Current, rainfall and tropical cyclones (for example).

It is recommended that research is undertaken, supported, reviewed and tapped into by the Board to investigate the likely effects of climate change on ENSO, ocean currents, sea surface temperature, reef calcification and growth, wave storminess, wave direction and rainfall intensity at Lord Howe Island (and hence impacts of climate change on coral reefs and shoreline alignment, for example). Furthermore, it is recommended that the reef at Lord Howe Island is managed to promote resilience under multiple potential climate change stressors (refer to Section 13.4.1).

Anthony and Marshall (2012) noted that because climate change is likely to amplify the disturbance regime for coral reefs, the fate of these ecosystems will increasingly be determined by their potential for recovery and long-term maintenance of structure, function and goods and services, that is their resilience. Resilience-based management requires that management goals for marine ecosystems

[57] However, there are examples of coral reefs that do thrive in highly acidified environments (Shamberger et al, 2014).

such as coral reefs be expanded to focus on process (eg recruitment success, algal removal rates), as well as state (eg coral abundance, density of fish).

As stated by Anthony and Marshall (2012), to preserve Australia's coral reefs for future generations, it is critical that management efforts are invested into understanding the factors that influence the resilience of ecosystems, and prioritise management efforts toward restoring and maintaining ecosystem resilience. Adaptive resilience-based management is likely to offer the best hope for marine ecosystems, such as the coral reef at Lord Howe Island, in the face of climate change.

8. EROSION/RECESSION COASTLINE HAZARDS

8.1 Preamble

Potential coastline hazards that could impact on the study area are defined in subsequent sections, namely:

- beach erosion (Section 8.2);
- shoreline recession (Section 8.3);
- stormwater erosion (Section 8.4); and
- slope instability in terms of various coastal hazard zones (Section 8.5).

Hazard lines are delineated in Section 8.6, with discussion on risk to assets in Section 8.7.

8.2 Beach Erosion (Storm Demand)

During storms, large waves, elevated water levels and strong winds can cause severe erosion to sandy beaches. The hazard of beach erosion relates to the limit of erosion that could be expected due to a severe storm or from a series of closely spaced storms (NSW Government, 1990).

The beach erosion hazard is analogous to the "storm demand" discussed in Section 7.7.1. On the NSW mainland, various methodologies consistently result in fully exposed open coast areas having an estimated 100 year ARI storm demand of 200m^3/m to 250m^3/m above mean sea level. At Lord Howe Island there are no known measurements of storm cut volumes, and storm cut numerical modelling was beyond the scope of the investigation reported herein, making it difficult to reliably estimate the 100 year ARI storm demand.

In Manidis Roberts Consultants (1993), a storm demand volume of 50m^3/m (ARI not stated) above LHITD (presently 0.144m AHD, that is close to 0m AHD) was adopted for Lagoon Beach and Cobbys Beach. This is considered to be a reasonable 100 year ARI value based on correlating storm demand to relative wave energy as explained below:

- Patterson Britton & Partners (1997) estimated a design wave height of 2.4m for design of protective works along Lagoon Beach, say 100 year ARI;
- 100 year ARI breaking wave heights along the NSW mainland that could cause erosion magnitudes of 250m^3/m are in the order of 6m (based on WorleyParsons, 2009);
- various authors have suggested that storm demand is proportional to wave energy, with wave energy being proportional to wave height squared;
- therefore, squaring the Lord Howe Island and NSW mainland wave height ratio, that is $(2.4/6)^2 = 0.16$ and multiplying this by the storm demand of 250m^3/m gives 40m^3/m above mean sea level as the storm demand estimate for Lagoon Beach and Cobbys Beach;
- for an approximate beach slope of 1:10 (vertical:horizontal), as typically occurs along these beaches, the additional volume of sand between mean sea level (1.2m AHD) and 0m AHD is about 12m^3/m;
- hence storm demand for these beaches can be estimated as 52m^3/m above 0m AHD, consistent with 50m^3/m above 0.1m AHD estimated by Manidis Roberts Consultants (1993).

To provide some conservatism, a present day 100 year ARI storm demand of 50m^3/m above 1m AHD was adopted herein.

To determine the position of the Immediate Coastline Hazard Line, the most recent 2011 photogrammetric profiles were used to define the pre-storm beach profile shape. To define the Immediate Hazard Line, the 50m^3/m (above 1m AHD) storm demand volume was applied to each photogrammetric beach profile to estimate the landward storm cut distance into the dune.

8.3 Shoreline Recession Hazard

8.3.1 Preamble

The hazard of shoreline recession is the progressive landward shift in the average long term position of the coastline (NSW Government, 1990). Two potential causes of shoreline recession are net sediment loss, and an increase in sea level, as outlined in Sections 8.3.2 and 8.3.3 respectively. It is also appropriate to discount (in the assessment of recession due to net sediment loss) any potential recession due to actual sea level rise that may have occurred over the measurement period of the photogrammetric data[58], as discussed in Section 8.3.4.

8.3.2 Long Term Recession Due to Net Sediment Loss

Long term recession due to net sediment loss is a long duration (period of decades), and continuing net loss of sand from the beach system. According to the sediment budget concept, this occurs when more sand is leaving than entering a beach compartment. This recession tends to occur when:

- the outgoing longshore transport from a beach compartment is greater than the incoming longshore transport;
- offshore transport processes move sand to offshore “sinks”, such as gutters within reef systems, from which it does not return to the beach; and/or
- there is a landward loss of sediment by windborne transport (NSW Government, 1990).

Shoreline recession due to net sediment loss should not be confused with beach erosion, with the latter resulting in a short term exchange of sand between the subaerial and subaqueous portions of the beach, not a net loss from the active beach system. Shoreline recession is therefore a long term process which is overlaid by short term fluctuations (erosion and accretion) due to storm activity.

The adopted long term recession rates due to net sediment loss were given in Section 7.7.2. For example, a 0.4m/year rate was adopted at the southern end of Lagoon Beach, which is equivalent to 15.6m at 2050 and 35.6m at 2100[59].

8.3.3 Long Term Recession due to Sea Level Rise

In general, a progressive rise in sea level may result in shoreline recession through two mechanisms: first, by drowning low lying coastal land, and second, by shoreline readjustment to the new coastal water levels. The second mechanism is probably the more important since a significant volume of sediment may move offshore as the beach seeks a new equilibrium profile (NSW Government, 1990).

[58] The photogrammetric data measurement period was from 1965 to 2011 at Lord Howe Island.
[59] The rates were applied relative to 2011 base profiles, and from 2011 it is 39 years to 2050 and 89 years to 2100.

Bruun (1962) proposed a methodology to estimate shoreline recession due to sea level rise, the so-called Bruun Rule. The Bruun Rule is based on the concept that sea level rise will lead to erosion of the upper shoreface, followed by re-establishment of the original equilibrium profile. This profile is re-established by shifting it landward. The concept is shown graphically in Bruun (1983), and can be described by the equation (Morang and Parson, 2002):

$$R = \frac{S \times B}{h + d_c} \quad (1)$$

where R is the recession (m), S is the long term sea level rise (m), h is the dune height above the initial mean sea level (m), d_c is the depth of closure[60] of the profile relative to the initial mean sea level (m), and B is the cross-shore width of the active beach profile, that is the cross-shore distance from the initial dune height to the depth of closure (m). This equation is a mathematical expression that the recession due to sea level rise is equal to the sea level rise multiplied by the average inverse slope of the active beach profile, with the variables as illustrated in Figure 34.

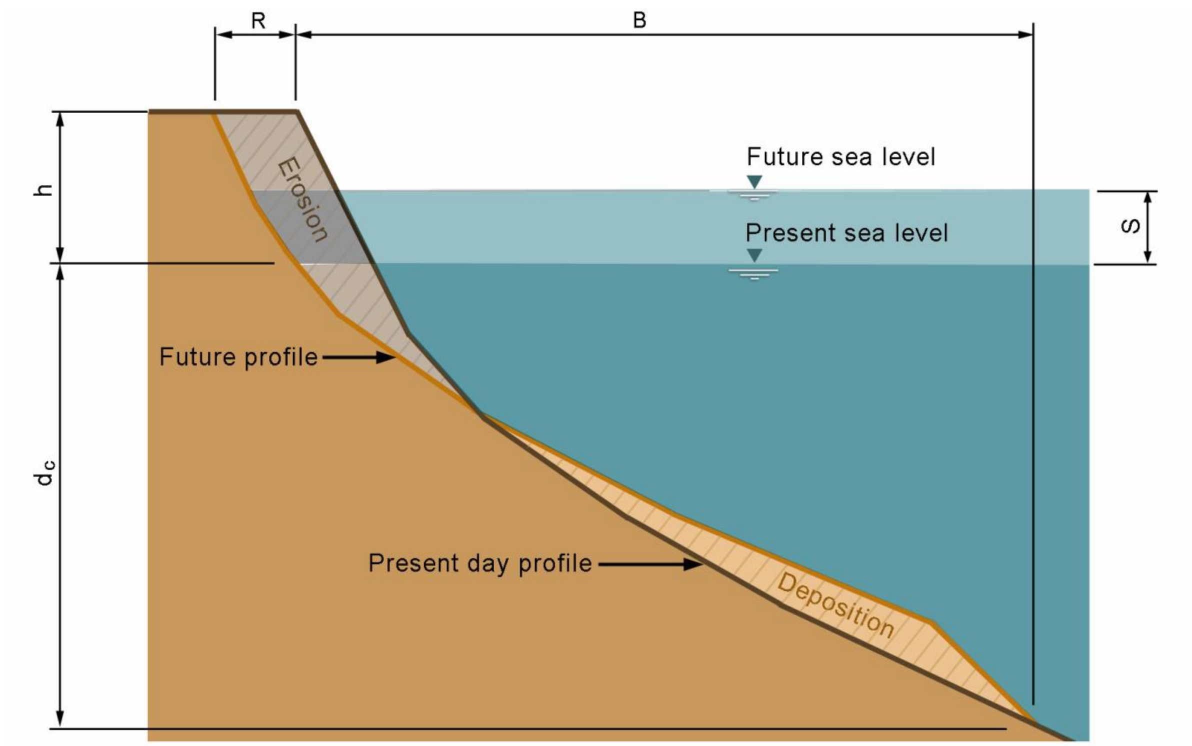


Figure 34: Illustration of variables in the Bruun Rule

Given the flat and shallow Lagoon offshore of Lagoon Beach and Cobbys Beach, with an excess of sand compared to an equilibrium profile, it is considered that only the subaerial beach face would

[60] The depth of closure is the water depth beyond which repetitive profile surveys (collected over several years) do not detect vertical sea bed changes, generally considered to be the seaward limit of littoral transport. The depth can be determined from repeated cross-shore profile surveys or estimated using formulas based on wave statistics. Note that this does not imply the lack of sediment motion beyond this depth (Szuwalski and Morang, 2001).

potentially adjust due to sea level rise. The inverse slope of the active beach profile (as used in the Bruun Rule) is about 10 for the beach face.

To apply this inverse slope to estimate long term recession due to sea level rise, it is necessary to discount sea level rise that has occurred from 1990 to present. This is because the adopted sea level rises of 0.4m at 2050 and 0.9m at 2100 are defined to be relative to 1990 (see Section 7.9.1).

As described by DECCW (2010b), there was approximately 3mm/year of global sea level rise since 1990. For 2011 base profiles (21 years since 1990), there was thus 63mm of sea level rise to discount (that is, about 0.06m) Therefore, the actual sea level rise to apply at 2050 in using the Bruun Rule is 0.4 minus 0.06, that is 0.34m. Similarly, the sea level rise to apply at 2100 is 0.84m.

Therefore, the projected “Bruun Rule” long term recession due to sea level rise at 2050 and 2100 is about 3.4m (10 multiplied by 0.34) and 8.4m (10 multiplied by 0.84) respectively.

At Lagoon Beach and Cobbys Beach at Lord Howe Island, there is the additional complexity of the coral reef acting to reduce wave heights entering the Lagoon. The amount of wave energy that can enter the Lagoon is dependent on the water level above the crest of the reef, as wave heights are limited by the depth of water over the reef crest.

Assuming that the coral reef does not keep up with sea level rise (that is, does not grow upward at the same rate as sea level rise), then it would be expected that the wave energy entering the Lagoon would increase over time, and in particular the 100 ARI wave height at the shoreline would increase by approximately the same magnitude as the increase in mean sea level relative to the reef crest elevation.

If the reef remains at the same elevation as present, it would be reasonable to assume that the 100 year ARI wave height at Lagoon Beach and Cobbys Beach would increase from 2.4m at present to 2.7m at 2050 and 3.2m at 2100. Assuming that storm demand is proportional to wave height squared, as discussed in Section 8.2, this is an increase in storm demand of about 10m^3/m at 2050 and 30m^3/m at 2100.

8.3.4 Consideration of Historical Recession Rates

Shoreline recession rates determined from historical data may be influenced by any sea level rise which occurred in the period of the historical record (from 1965 to 2011 at Lord Howe Island). That is, although any long term recession that has occurred over the historical record would mainly be expected to have been caused by net sediment loss, given that there has also been some sea level rise over the historical record it can be argued that any historical long term recession has been partially caused by sea level rise.

Averaged around Australia, the relative sea level rise from 1920 to 2000 was about 1.2mm/year (CSIRO Marine Research, 2004), which is equivalent to a shoreline recession of about 0.01m/year at Lord Howe Island (considering Bruun Rule related recession only and assuming that the reef has maintained grown at least at the rate of sea level rise) . This rate is relatively low and can be ignored for practical purposes. It is not considered warranted to adjust (reduce) the long term recession due to net sediment loss estimates noted in Section 8.3.2.

8.4 Stormwater Erosion Hazard

During major stormwater runoff events, stormwater that is collected from back beach areas and discharges into coastal waters can cause significant localised erosion to the beach berm. This in turn can allow larger waves to attack the beach and can cause migration of the stormwater discharge entrance if not structurally contained (NSW Government, 1990). Flow from stormwater pipes and outlets on beaches can also potentially scour the surrounding sand, creating erosion zones.

In the study area there are no stormwater outlets of significance discharging onto beaches (there are outlets in the runway revetment), with stormwater related scour only occurring at the entrances to watercourses such as Old Settlement Creek, Cobbys Creek and Soldiers Creek (with only Cobbys Creek in the area covered by photogrammetric data). Within the limitation of the spacing of photogrammetric profiles for hazard definition, natural long-term lowering of beach berms surrounding Cobbys Creek is explicitly accounted for in the volumetric analysis defining hazard line positions. That stated, it should be recognised that migration of the entrance of Cobbys Creek is possible.

8.5 Coastline Hazard Zones

For sandy areas, based on Nielsen et al (1992), a number of coastline hazard zones can be delineated as shown in Figure 35.

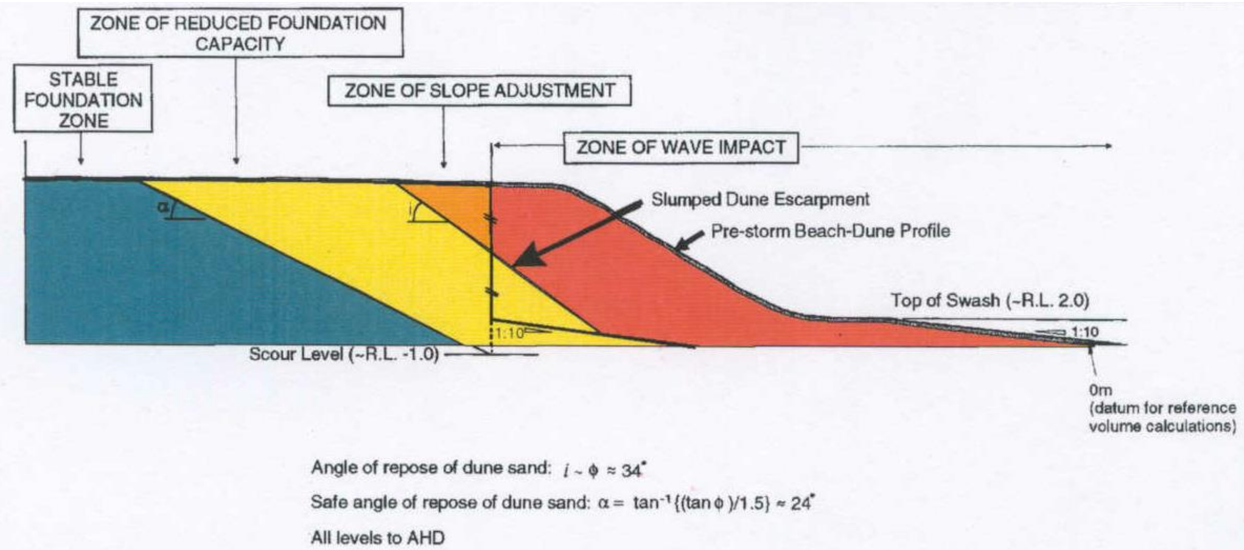


Figure 35: Schematic representation of coastline hazard zones (after Nielsen et al, 1992)

The *Zone of Wave Impact* delineates an area where any structure or its foundations would suffer direct wave attack during a severe coastal storm. It is that part of the beach which is seaward of the beach erosion escarpment. It is that part of the beach which is seaward of the beach erosion escarpment[61] (as defined by the beach erosion hazard, see Section 8.2).

A *Zone of Slope Adjustment* is delineated to encompass that portion of the seaward face of the beach that would slump to the natural angle of repose of the beach sand following removal by wave erosion

[61] The beach erosion escarpment is the steep (usually shore-normal) slope that is formed on a sandy beach when there is beach erosion, forming the link between the eroded and uneroded sections.

of the design storm demand. It represents the steepest stable beach profile under the conditions specified.

A *Zone of Reduced Foundation Capacity* (ZRFC) for building foundations is delineated to take account of the reduced bearing capacity of the sand adjacent to the storm erosion escarpment. Nielsen et al (1992) recommended that structural loads should only be transmitted to soil foundations outside of this zone (ie landward or below), as the factor of safety within the zone is less than 1.5 during extreme scour conditions at the face of the escarpment. In general, without the protection of a terminal structure such as a seawall, dwellings/structures located with the ZRFC and not founded on deep piles would be considered to have an inadequate factor of safety.

8.6 Delineation of Hazard Lines

Immediate (as of 2011), 2050 and 2100 Hazard Lines (defined at the landward edge of the Zone of Slope Adjustment) are depicted in Figure 36 (for Lagoon Beach as far south as the Seabee revetment) and Figure 37 (for the Seabee revetment section of Lagoon Beach, airport revetment area, and Cobbys Beach).

In deriving the hazard lines, an entirely sandy subsurface was assumed, that is existing protective works were ignored. While the Seabee revetment and airport revetment remain in place, the hazard lines would not be realised in these areas[62]. However, the extent of erosion/recession in these areas if the protective works were not in place (as per the derived hazard lines[63]) indicates the importance of maintaining these works to avoid damage to Lagoon Road and the airport runway.

The location of an asset landward of the Immediate Hazard Line does not mean it could not be affected by coastal erosion at present, rather that there is a low probability (in the order of 1% each year) of erosion extending landward of the Line at present (as of 2011).

[62] It is recognised that there are rocky areas landward of Lagoon Road where it extends along the Seabee revetment, that would limit the realisation of long term hazard lines in this area if the seawall failed.
[63] In practice, if the airport revetment failed and was not rebuilt there would be some smoothing of the lines depicted in in the vicinity of the airport in Figure 37.

Figure 36: Immediate, 2050 and 2100 Hazard Lines (at landward edge of ZSA) at Lagoon Beach (north of Seabee revetment)

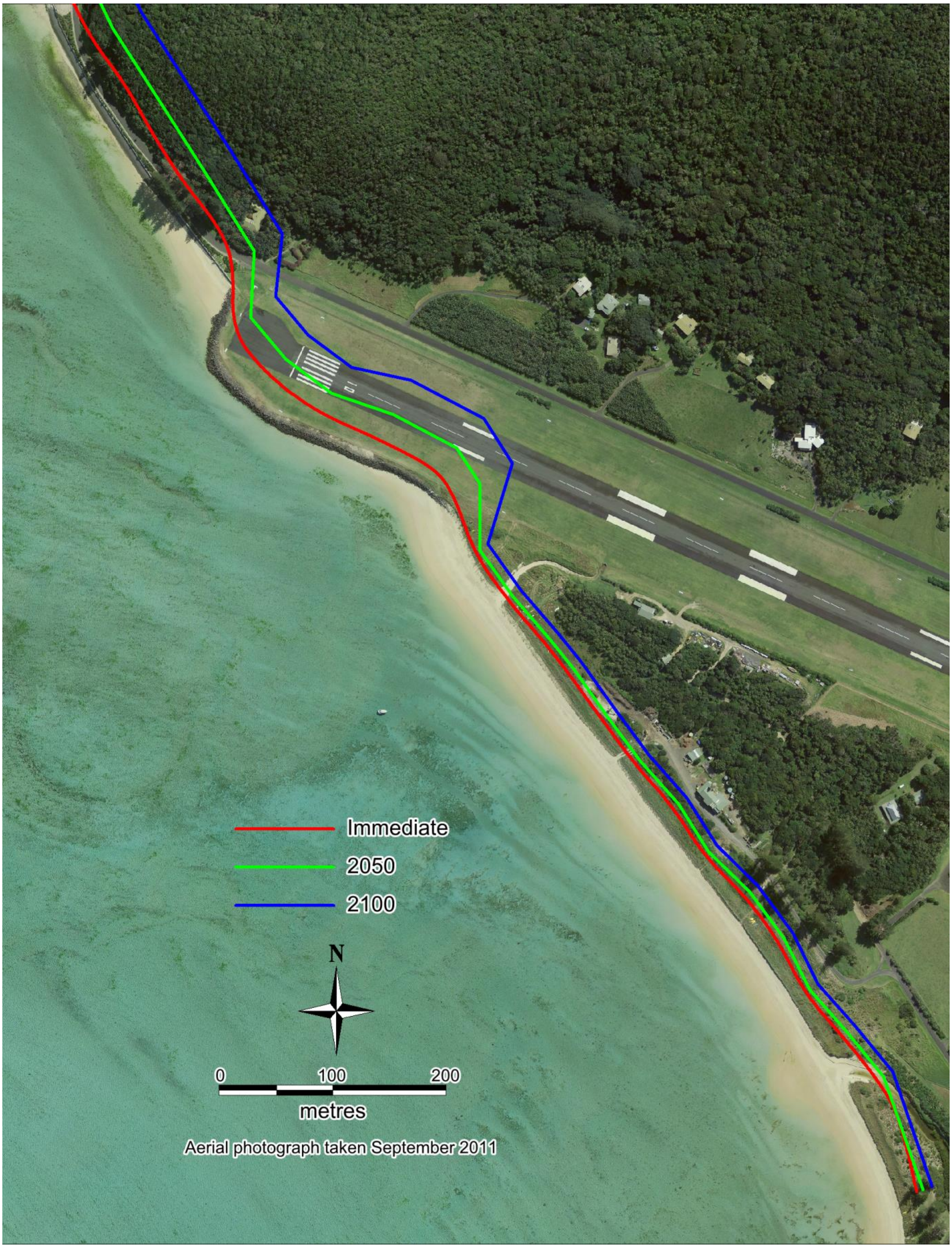


Figure 37: Immediate, 2050 and 2100 Hazard Lines (at landward edge of ZSA) at Seabee revetment, airport revetment and Cobbys Beach

8.7 Risk to Assets

The key assets at immediate risk of damage at Lagoon Beach and Cobbys Beach are Pinetrees boatshed and Lagoon Road near the bag wall. Considering 2050 and 2100 timeframes, the boatsheds at the northern end of Lagoon Beach begin to become at risk, as does the Aquatic Club. Without the protection of the Seabee revetment and rock revetment, Lagoon Road and the runway would be at immediate risk of damage, indicating the importance of maintaining these structures.

In August 2012, the erosion escarpment at Pinetrees boatshed was measured as being 7.6m from the seaward face of the structure, with the deck seaward of the boatshed within 1m of the escarpment (Figure 38).

Figure 38: Erosion escarpment adjacent to deck at Pinetrees boatshed in August 2012

9. CLIFF STABILITY

Woodroofe et al (1995) estimated that the calcarenite cliffs at Neds Beach were formed around 120,000 to 140,000 years ago. They considered that sediments were deposited by aeolian processes and formed over the underlying basalt during the Last Interglacial period (prior to the present Holocene interglacial period) when sea level was 2m to 4m above present levels.

The Neds Beach Calcarenite is composed of well-rounded and polished lithoclasts of coral, coralline algae, shell, foraminifera and microgastropods (Woodroofe et al, 1995). The cliff at the SE end of Neds Beach was considered by Woodroofe et al (1995) to be undergoing active erosion.

Further discussion on cliff stability is provided in Section 13.4.4.

10. COASTAL INUNDATION

Areas below about 3m AHD would be expected to be at particular risk of inundation. There are no areas of infrastructure at Lagoon Beach and Cobbys Beach below that elevation. Areas between 3m and 4m AHD in elevation may become subject to inundation over the long term under sea level rise.

The 3m, 4m and 5m AHD contours along the Lagoon Beach and Cobbys Beach shoreline are depicted in Figure 39.

It is evident that the airport is the most extensive area with elevations around 4m AHD.

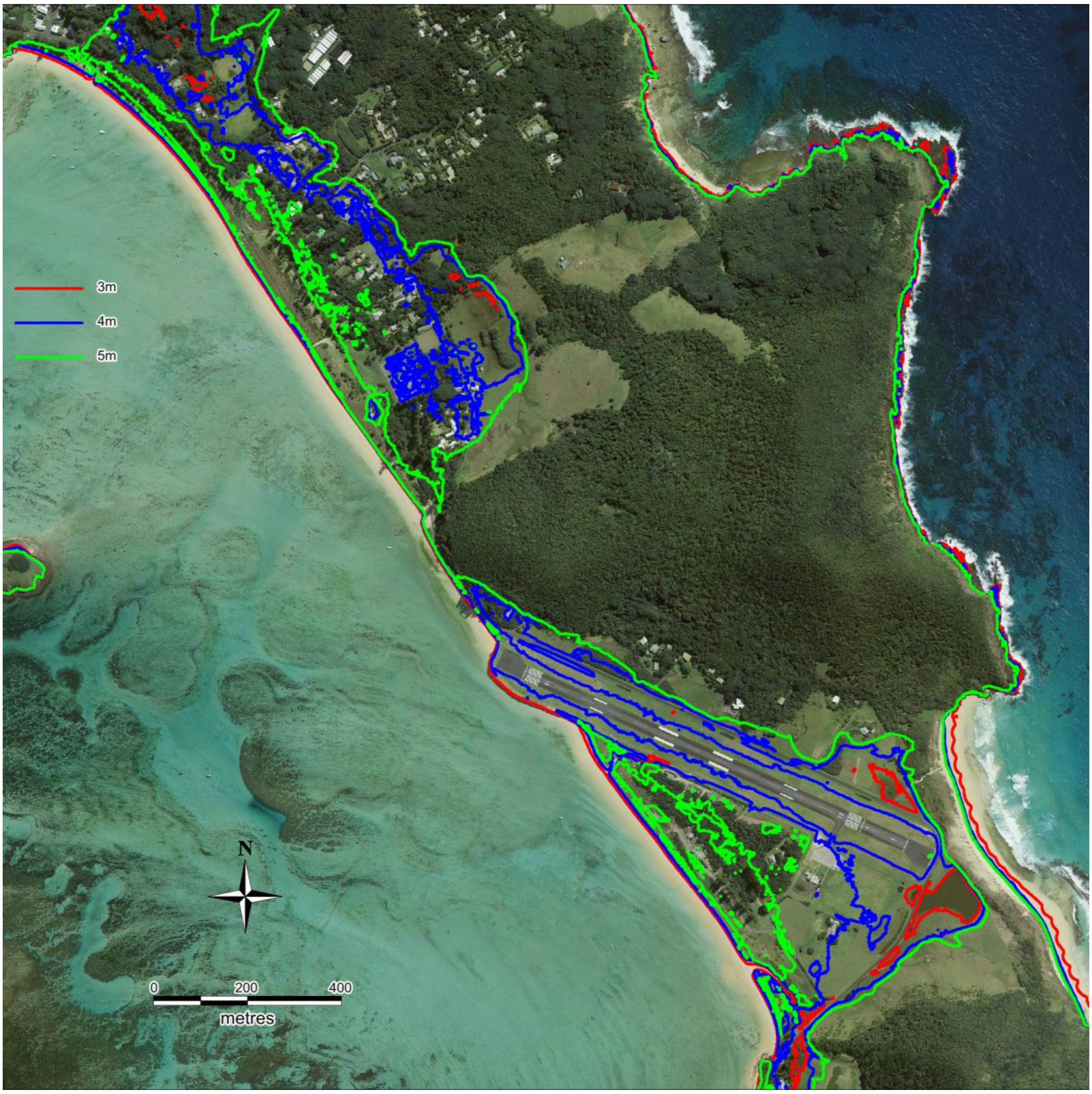


Figure 39: 3m, 4m and 5m AHD contours along the Lagoon shoreline

11. WATERCOURSE ENTRANCE MANAGEMENT

11.1 Overall Entrance Management Principles

There were three Intermittently Closed and Open Lakes and Lagoons (ICOLLs) identified in the Brief for consideration with regard to entrance management, namely Old Settlement Creek, Cobbys Creek and Soldiers Creek. Overall entrance management principles that should apply at all of these creeks are outlined below in this Section. Some specific comments on levels and issues at the particular creeks are provided in Sections 11.2, 11.3, and 11.4 respectively.

All these creek systems contain Sallywood Swamp Forest (also known as Lagunaria Swamp Forest), which is a Critically Endangered Ecological Community in NSW (found only at Lord Howe Island). This is a plant community dominated by the Sallywood tree. Other species found in this community include Mangroves, Kentia Palm, Cottonwood Hibiscus and Blackbutt. Sallywood Swamp Forest is found in very limited areas of Lord Howe Island, in low sites that are occasionally inundated (OEH, 2014a).

OEH (2014a) noted that key threats to the Sallywood Swamp Forest were clearing, exposure to winds, tramping by cattle and weed invasion. It is recommended that the Board continues to manage the Sallywood Swamp Forest areas through preventing clearing, providing wind protection, excluding cattle and through weed control.

OEH (2014b) noted that water regimes were a key driver of the existence of Sallywood Swamp Forest community as it occurs in low lying areas, often near the outlets of small creeks. OEH (2014b) also considered that future impacts with rising sea levels were likely to lead to an encroachment of mangroves into the community and necessitate its movement upslope onto existing grazing land, should that be available. It is recommended that the Board investigates opportunities to expand Sallywood Swamp Forest communities upslope where available, in liaison with landowners.

The Sallywood Swamp Forest can be adversely impacted by ingress of saline (ocean) waters into the creek systems (David Kelly, Manager Environment & Community Development, Lord Howe Island Board, personal communication). The Sallywood Swamp Forest is also found in swampy areas, but it is unknown how critical the level and frequency of freshwater inundation is for maintaining the health of the vegetation community[64].

Where possible, it is recommended that a natural entrance opening regime is maintained, that is no intervention, unless entrance management is required to enhance the Sallywood Swamp Forest or there is a particular need to reduce inundation of infrastructure (but only where this would not adversely impact on the Sallywood Swamp Forest).

The key effect of entrance openings in terms of maintaining the health of the Sallywood Swamp Forest is considered to be the ingress of saline water. If the health of the Sallywood Swamp Forest deteriorates under a natural entrance opening regime (ie with no human intervention in the breakout and closure process), then it would be necessary to intervene in this process to reduce the ingress of saline water. Saline intrusion could be reduced by:

[64] Scientific/engineering citation databases were searched in an attempt to find literature on the desirable frequency of inundation of Sallywood Swamp Forest, with no relevant information found.

- mechanically closing off an entrance immediately after a breakout event by redistributing sand near the entrance, thus reducing the duration (and hence volume) of saline intrusion; and/or
- maintaining the beach berm level seaward of a creek at a higher level, again by redistributing sand near the entrance, which would reduce the frequency of openings and hence provide fewer opportunities for saline intrusion to occur; and/or
- mechanically opening an entrance (if that was required) on a low to rising tide, which would reduce the efficiency of the breakout process and lead to less entrance scour due to faster equilibration of creek and ocean water levels.

All of the above actions would be counterproductive to any requirements to manage an entrance to reduce inundation levels to protect infrastructure. To manage an entrance for flood mitigation purposes, it would be most effective to:

- maintain the beach berm level seaward of a creek at a lower level (as a 'notch' or 'saddle'), which would increase the frequency of openings and reduce the water level required to induce natural breakout; and/or
- mechanically open an entrance (if that was required) at high tide, which creates the most efficient breakout process as it leads to the longest duration of time that creek levels are higher than the ocean and hence able to drive a seaward flow to drain the creek.

There may be times during extended dry periods when it is desirable to flush creeks that have stagnant pools. This could be achieved by a manual entrance opening, although it must be recognised that this would cause saline water intrusion as ocean waters enter the creek, with some reduction in salinity as fresh groundwater would also enter the creek. It would therefore be necessary to monitor Sallywood Swamp Forest health after any such openings were undertaken, and alter entrance opening practices if required.

It should also be recognised that creek openings introduce suspended sediment and nutrients into the Lagoon, which may impact on coral and seagrass within the Lagoon. For example, plumes of turbid creek water were evident in the Lagoon seaward of the three creeks after rainfall-runoff induced natural openings in August 2012. It is recommended that catchment management practices are adopted to minimise the mobilisation of sediment and nutrients from the surrounding catchments into the creeks during rainfall-runoff.

Given the sensitivity of the Sallywood Swamp Forest to any mechanical entrance opening, it is recommended that:

- there is community education that landowners are not to open creek entrances without Board approval, with legislative changes to make this unlawful if required;
- records are kept by the Board's Administration of the date of natural and mechanical entrance openings and closures;
- berm levels are regularly surveyed, say quarterly;
- water quality within the creek systems is monitored, including salinity levels along the creeks moving downstream to upstream (and variations with depth);
- the health of the Sallywood Swamp Forest is monitored and assessed by the Board's Administration in relation to entrance openings and closures; and
- the entrance opening regime is altered by the Board's Administration as required in terms of maintaining the health of the Sallywood Swamp Forest, protecting infrastructure, and flushing stagnant pools.

If berm levels increase due to sea level rise (which is expected), there may be little change to saline intrusion in the future under a natural entrance opening regime, or even less saline intrusion as opening frequency may reduce (as creek levels would need to be higher to induce natural breakout). However, there are additional complexities in this process such as the potential for rainfall patterns to alter under climate change, and for groundwater to become more saline with sea level rise. This emphasises the importance of continued monitoring of Sallywood Swamp Forest areas into the future.

It may also be possible to reduce saline intrusion by regrading creeks (increasing bed levels in the vicinity of the Sallywood Swamp Forest) or introducing weir or gate like structures downstream of the Sallywood Swamp Forest. Additional investigations would be required to assess the feasibility and environmental impacts of such works.

11.2 Old Settlement Creek

At Old Settlement Creek, there is no significant surrounding infrastructure known to require an entrance opening trigger to reduce the risk of flooding, with the lowest nearby structures above 4m AHD[65]. An electrified fence located on the south bank of Old Settlement Creek about 75m north of the entrance (Figure 41) can 'short' out due to inundation, but it is recommended that (in consultation with the leaseholder) the fence design be changed (for example not electrifying the bottom rail and using barbed wire if required) or the fence be relocated to manage this, rather than introducing an opening trigger for this issue alone.

The beach berm at the entrance to Old Settlement Creek was at a level of about 2.6m AHD in an August 2011 survey (provided by the Board), and also in October 2012 LiDAR data. The Sallywood Swamp Forest is located about 300m upstream from the entrance (Figure 41). A photograph of the creek entrance after a rainfall-runoff induced natural opening in August 2012 is provided in Figure 40.

There is a substantial delta of sand formed within the Lagoon seaward of Old Settlement Creek, extending about 70m cross-shore and 110m alongshore, as visible in 2011 aerial photography (Figure 41). Observing 1975, 1984 and 2001 photography, it was evident that:

- in 1975, there was an entrance delta of similar dimensions as present (but located further south-east);
- the 1975 and 1984 entrance positions were similar;
- between 1984 and 2001, the entrance migrated about 50m north-west; and
- the delta also migrated north-west with this creek migration (that is, the delta has been positioned over time to be centred at the creek outlet).

There may be consideration of using this delta as a source of sand for beach nourishment, subject to assessment of sediment properties, environmental assessment and monitoring of effects on coastal processes at Old Settlement Beach. There are likely to be several thousands of cubic metres of sand in the delta that could potentially be removed without adversely impacting on coastline hazards at Old Settlement Beach or other areas. If this was considered, this could be undertaken progressively (with monitoring) to reduce the potential impacts. The fact that the Old Settlement Beach area has a relatively sheltered wave climate means that any impact of removal of delta sand on coastal processes is likely to be limited.

[65] Note that the deck level over the bridge at Old Settlement Creek is 3.4m AHD.

There are two cattle crossings (muddy tracks) over Old Settlement Creek (see Figure 41) that, due to trampling and associated erosion, may be sources of sediment and nutrients to be mobilised into the creek. It is recommended that there is consideration of works (such as hardening the crossings) to reduce potential mobilisation of sediment in these areas.

Figure 40: Natural opening of Old Settlement Creek, 31 August 2012

Figure 41: Aerial photograph of Old Settlement Creek entrance, with delta evident

11.3 Cobbys Creek

At Cobbys Creek, there is surrounding infrastructure below 4m AHD. This includes the area surrounding a dwelling on Portion 191 which is located south-west of the entrance (Figure 43). The floor level of the dwelling at Portion 191 is unknown, but surrounding ground levels are about 3.4m AHD to the north and south, 3.8m AHD to the east, and 4.0m AHD to the west (based on October 2012 LiDAR data). Lagoon Road is at a level of about 3.8m AHD where it crosses the creek.

The beach berm at the entrance to Cobbys Creek was at a level of about 2.8m to 2.9m AHD in October 2012 LiDAR data. It is understood that there is a Sallywood Swamp Forest community located upstream of where Lagoon Road crosses Cobbys Creek (Figure 43). A photograph of the creek entrance after a rainfall-runoff induced natural opening in August 2012 is provided in Figure 42.

There is a delta of sand formed within the Lagoon seaward of Cobbys Creek, extending about 30m offshore and 60m alongshore, as visible in 2011 aerial photography (Figure 43). The entrance migrated about 30m north from 1965 to 2011, an average rate of about 1.5m/year, although the entrance appears to have been relatively stable since 2001[66]. The delta has only been visible in aerial photography since 2011 (based on examination of 1965, 1975, 1984 and 2001 dates), but this may be a function of entrance closure at the time of earlier photographs, and the delta at Cobbys Beach being a transient feature due to longshore sand transport.

As for Old Settlement Creek, there may be consideration of using the Cobbys Creek delta as a source of sand for beach nourishment. There is likely to be in the order of 1,000m^3 metres of sand in the delta that could potentially be removed without adversely impacting on coastline hazards at Cobbys Beach or other areas.

[66] Based on advice from Board staff, it is understood that some of this migration may have been artificial.

Figure 42: Natural opening of Cobbys Creek, 31 August 2012

Figure 43: Aerial photograph of Cobbys Creek entrance, with delta evident

11.4 Soldiers Creek

At Soldiers Creek, the adjacent Lagoon Road is at a level of about 3.3m AHD at its northern arm, and 3.1m AHD (at its lowest point) near its southern arm. Paddocks located adjacent to Lagoon Road in this area are generally at a level of about 3.4m AHD, with some areas as low as 2.7m AHD near the northern arm. Surrounding houses are above 4.0m AHD (all levels based on October 2012 LiDAR data).

The beach berm at the entrance to Soldiers Creek was at a level of about 2.4m AHD in October 2012 LiDAR data. It is understood that there is a Sallywood Swamp Forest community located on the western side of Lagoon Road in the northern arm (Figure 45). A photograph of the creek entrance after a rainfall-runoff induced natural opening in August 2012 is provided in Figure 44.

Given that the Sallywood Swamp Forest at Soldiers Creek is so close to the entrance, there may be limited opportunities to lower berm levels and maintain a viable Sallywood Swamp Forest community at this location. If waterlogging and inundation is an issue for road access and landholdings in this area, there may be consideration of earthworks (cut and fill) in targeted areas to raise ground levels where they are low lying, subject to environmental assessment.

There is a delta of sand formed within the Lagoon seaward of Soldiers Creek, extending about 30m offshore and 30m alongshore, as visible in 2011 aerial photography (Figure 45). Given the surrounding rocks, and that this delta may only be a veneer of sand over rock, using this sand as a beach nourishment source is unlikely to be considered in preference to the Old Settlement Creek and Cobbys Creek sites.

Figure 44: Natural opening of Soldiers Creek, 31 August 2012

Figure 45: Aerial photograph of Soldiers Creek entrance, with delta evident

12. IMMEDIATE MANAGEMENT ACTIONS

12.1 Key Coastline Management Issues

The two key coastline management issues at Lord Howe Island are located in the receding area north of the bag wall. The two issues relate to the close proximity of the erosion escarpment to:

- Lagoon Road (the only road access to the Airport from the main settlement area and all areas north of the Airport) and an underground high voltage cable and telecommunications cable; and
- the Pinetrees boatshed (and deck located seaward).

From an overall community and economic perspective, the risk to the road and cables can be considered as the more significant issue. The road and high voltage cable are the responsibility of the Board, while the telecommunications cable is the responsibility of Telstra. The Pinetrees boatshed (an improvement on Permissive Occupancy land) is privately owned.

The Board is proposing to issue a new permissive occupancy for the Pinetrees boatshed site with the following special conditions:

- "that the occupants acknowledge the erosion risk and expressly agree to waive any claim for negligence, against the State of NSW, the Minister and the Lord Howe Island Board, and agree to indemnify the State of NSW, the Minister and the Lord Howe Island Board against any and all actions arising from loss or damage to the structures arising from coastal erosion; and
- that the Permissive Occupancy will be terminated when coastal erosion immediately threatens the structures including the boatshed and decking".

Should the Permissive Occupancy be granted, it would be necessary for the Board to implement an inspection regime that ensures that it is able to expeditiously identify this circumstance and any remedial actions and accordingly recommend to the Minister that the Permissive Occupancy be terminated (if required).

The receding dunal area at the southern end of Lagoon Beach is understood to be critical habitat for the Lord Howe Island skink (*Oligosoma lichenigera*[67]), which is listed as vulnerable in Schedule 2 of the *Threatened Species Conservation Act 1995*.

The wedge-tailed shearwater (*Puffinus pacificus*[68]), which is a migratory bird, also uses this area to breed. Based on Department of the Environment (2013), this bird arrives at Lord Howe Island between early August and early September, and lays eggs between late November and early December. The young birds fledge (begin to fly) from late April to early May.

Immediate management actions to reduce the risk of undermining at Lagoon Road (for which investigations should be commenced or actions undertaken now) are listed in Section 12.2. Advantages and disadvantages of potential future management actions for this area, that may be considered as part of a Coastal Zone Management Plan (CZMP), are discussed in Section 13.2.

[67] Formerly *Pseudomoia lichenigerum*.
[68] Also known as *Ardenna pacifica*.

The effects of the actions listed for the Lagoon Road area on coastline hazards at Pinetrees boatshed are discussed in Section 12.3. Potential future actions for the Pinetrees boatshed area, that the Permissive Occupancy holder may consider implementing with consent, are discussed in Section 13.3.

12.2 Recommended Immediate Actions to Manage Erosion/Recession Risks to Lagoon Road and Underground Cables

12.2.1 Preamble

Recommended immediate interim actions to manage erosion/recession risks to Lagoon Road are outlined below, from highest to lowest priority. It should be recognised that these are interim management actions given that a Coastal Zone Management Plan (CZMP), as per Part 4A of the *Coastal Protection Act 1979*, has not been completed for the study area. However, these actions likely to be considered in any future such CZMP.

It is considered that the “do nothing” option is unacceptable given the importance of Lagoon Road and adjacent underground cables, ongoing long term recession in the area, and the likelihood of further recession in the area in the future due to sea level rise.

12.2.2 Action 1: Discontinue Beach Scraping

It is recommended that cross-shore beach scraping (in isolation) is discontinued at Lagoon Beach, and sand is added to the eroding/receding areas at the southern end of the beach (from near Pinetrees boatshed to the bag wall) by:

- undertaking alongshore sand relocation, see Section 12.2.4; and/or
- undertaking beach nourishment, that is using sand sourced externally from Lagoon Beach (such as sand from Blinky Beach), see Section 12.2.5.

In both cases, it is recommended that monitoring of beach profile changes over time is carried out by undertaking surveys along Lagoon Beach. Monitoring should be undertaken in both the source and the placement areas (see Section 12.2.6). Such monitoring would assist in confirming the understanding of coastal processes and informing any future campaigns of alongshore sand relocation and beach nourishment.

12.2.3 Action 2: Develop Emergency Action Plan

Considering the importance of Lagoon Road and adjacent underground cables, and the impact on the Lord Howe Island economy if they were damaged, it is recommended that an investigation is undertaken of the feasibility of emergency protective works. Specifically, this would investigate the feasibility of generating a stockpile of large boulders for use as emergency protective works (to form a randomly placed rock revetment by tipping over the erosion escarpment if required), and the suitability of existing plant and equipment on the island to be used to complete these works. It is considered that rock is the only effective material to use as emergency protection at Lord Howe Island.

Rock near Little Island has been used in the past at Lord Howe Island for protective works. Whatever rock source is selected, some assessment or testing of the rock to determine its suitability (such as mass, shape[69] and durability) for use as protective works would be recommended.

It would also be necessary to ensure planning approvals are in place for such works if they are ever required (see Section 14), and to develop triggers to undertake actions. The investigations should be undertaken expeditiously as Lagoon Road and the adjacent cables would not be able to be protected if threatened in a coastal storm otherwise.

Advantages of emergency rock protection include the following (assuming that suitable rock is available and environmental impacts are found to be acceptable):

- would provide interim protection to the important Lagoon Road asset until long term solutions had been adopted as part of a Coastal Zone Management Plan;
- rock would not need to be placed until (if) required, in response to an agreed trigger;
- relatively simple construction method;
- can be placed during storm conditions; and
- rock could be removed after placement if required.

Disadvantages of emergency rock protection include the following:

- requires stockpiling of rock in advance of a storm;
- potential visual and beach amenity impacts;
- placement would not be under controlled conditions; and
- potential additional localised erosion at ends of the rock protection ('end effects').

12.2.4 Action 3: Alongshore Sand Relocation

Alongshore sand relocation would involve moving sand (alongshore) to the eroding/receding area at the southern end of Lagoon Beach, sourcing from prograding areas at least 150m north of Pinetrees boatshed. The sand would be sourced by scraping a shallow 0.3m thick layer of coarser sediment near the waterline. Sand could also be sourced from where it is building up at the slipway near the boatsheds at the northern end of Lagoon Beach. Where possible, it is better to source coarser sand as this would be less likely to be transported following placement (or would be transported more slowly) compared to finer sand.

The sand should be placed by spreading it over the entire beach profile, for example avoiding placement of large mounds of sand against the erosion escarpment as this may lead to sand being blown into vegetated dunal areas, as discussed in **Appendix B**, Section B4[70].

Records should be kept by the Board of the dates of each relocation campaign, approximate quantities moved, depth of source sand removed, and source and placement locations (marked on an aerial photograph).

Alongshore sand relocation has the following advantages:

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[69] The rocks near Little Island are relatively rounded, which are less suitable to use as protective works than angular rocks which tend to interlock.

[70] This is different to "longshore and cross-shore beach scraping" as discussed in Section 7.6.3, as it avoids mounding of sediment at the eroding dune face.

- relatively low cost
- likely low environmental impact (and low cumulative impact with ongoing operations);
- able to be undertaken using existing Board plant and equipment;
- improves beach amenity at placement site; and
- can be trialled and monitored to assess effectiveness.

Alongshore sand relocation would need to be ongoing, and the erosion risk to assets may continue unless significant volumes of sand were moved. Planning approvals would need to be in place for these works (see Section 14), with potential environmental impacts on both the source and placement areas considered. It is understood that the Board has a current NSW Marine Parks Permit (of 12 months duration) for "works on the foreshore of the Lord Howe Island Lagoon at Windy Point including relocation of sand for emergency works only" (Permit No. LHIMP/W/2013/002a), which expires on 16 September 2014. This may not allow alongshore sand relocation works in non-emergency periods, so an additional permit may be required as it is recommended that alongshore sand relocation works are carried out outside of emergency periods.

In the past (from 1 July 2011 to 30 June 2012), the Board has had a NSW Marine Parks Permit for "removal of sand adjacent to the LHI slipway [at the northern end of Lagoon Beach] to provide access for vessel maintenance and inspections" (Permit No. LHIMP/W/2011/04), but that this has not been renewed. This only allowed for removal of sand from the specific slipway location at the northern end of Lagoon Beach[71], and was not a permit for alongshore sand relocation.

12.2.5 Action 4: Beach Nourishment

Beach nourishment would involve adding sand to the southern end of Lagoon Beach (along the boatshed to bag wall area, with a general preference for greater placed volumes further south), using sand derived from a source external to Lagoon Beach.

There is a reasonable sand source at the Blinky Beach dunes. These dunes need to be periodically lowered to meet aviation requirements. It is understood that limited quantities of sand sourced from Blinky Beach dune lowering in 2013 were used to nourish Lagoon Beach (sand was generally pushed seawards from the dune at Blinky Beach rather than being removed, with a stockpile of only 2,000m^3 of removed sand now being available for community use) . Another sand source would be the prograding areas of Cobbys Beach. Where possible, it is better to use coarser sand for beach nourishment as this would be less likely to be transported following placement (or would be transported more slowly) compared to finer sand.

Records should be kept by the Board of the dates of any nourishment campaign, approximate quantities moved, and source and placement locations (marked on an aerial photograph).

The advantages of beach nourishment are similar to those for alongshore sand relocation. As for alongshore sand relocation, beach nourishment would need to be ongoing, the erosion risk to assets may continue unless significant volumes of sand were placed, and planning approvals would need to be in place for the works (see Section 14). A sediment tracing study (Section 12.2.7) would provide valuable insight into the likely movements of nourished sand.

[71] With sand excavated in areas below (ie seaward of) the high water mark meant to be placed to the side of the rails, and sand excavated in in areas above (ie landward of) high water mark meant to be removed via a truck and stockpiled for future emergency works (sand nourishment of Windy Point) and community purposes.

12.2.6 Action 5: Beach Profile Surveys

To assess the effectiveness of alongshore sand relocation and beach nourishment, as well as ongoing natural movement of sediment along Lagoon Beach and Cobbys Beach, it would be important to monitor beach changes. This could be completed through regular surveying of shore-normal beach profiles. Monthly surveys would be desirable, or at least quarterly to capture seasonal effects. It would also be beneficial to undertake surveys immediately after significant beach erosion events and during subsequent beach recovery.

It would be convenient to coincide these surveyed profiles with selected photogrammetric profile locations. With reference to the profile locations in **Appendix B**, if possible, the following 22 profile locations should be surveyed: Profiles 1, 5, 9, 11, 14, 17, 19, 21 to 27, 29, 31, 37 to 40, 43 and 47.

Profiles should extend from 5m landward of the sand/vegetation interface (or 5m landward of the top of the erosion escarpment where vegetation is absent) to as far seaward as a low tide wading depth (it is expected that a distance of 50m seaward of the low tide waterline would be captured). All major changes in grade should be captured. It is recommended that levels be gathered to an accuracy of ± 50 mm. With each profile separately identified, data should be recorded in an ASCII text file or Excel spreadsheet with columns X, Y, Z, chainage and feature, where:

- X and Y are coordinates in metres to the Map Grid of Australia (GDA 94) Zone 57 to at least 1 decimal place;
- Z is elevation in metres AHD to at least 2 decimal places;
- chainage is the distance along the profile from the most landward data point; and
- feature can be used to record relevant information such as the location of the sand/vegetation interface and waterline at a particular time.

The same alignment and landward starting location should be used for a particular surveyed profile over time (that is, ongoing surveys should have the same landward starting location each time a particular profile is surveyed). Coordinates of the photogrammetric profile locations are available to assist in coinciding the survey lines with the photogrammetry.

Use of sand tracing (Section 12.2.7) may reduce some of the requirements for ongoing beach profile surveys.

12.2.7 Action 6: Sand Tracing Study

As outlined herein, the sediment transport patterns in the Lagoon at Lord Howe Island are complex. It is recommended that a sediment tracing study is undertaken to provide a more informed and accurate understanding of where sand is moving and what processes drive this movement. This would involve using inert fluorescent synthetic particles to mimic sand properties, and tracking the movement of these particles from various locations in the Lagoon over say 18 months.

This would assist in determining the relative significance of longshore and cross-shore processes due to tidal, wind-wave and swell-wave transport, with a particular focus on the fate of material transported and eroded from beaches. This would enable an improved understanding of coastal processes to be developed, and would give greater clarity as to the most appropriate long term management actions for the beaches in the Lagoon, for example in terms of potential impacts and likely effectiveness if constructed. A sediment tracing study would also assist in understanding the long term sustainability of alongshore sand relocation and beach nourishment.

The fluorescent sediment tracing technique is an established and environmentally acceptable technique for measuring sediment transport. It has been applied in many studies in Australia, including a current investigation at Old Bar in NSW which is being funded by OEH and Greater Taree Council and being undertaken by Environmental Tracing Systems Ltd and Haskoning Australia. Other tracing studies in Australia and overseas that have been undertaken include investigations for the US Army Corps of Engineers, Port of Townsville, North Queensland Bulk Ports, and Port Hedland Port Authority. Tracing can be expected to provide a reliable means of determining sediment transport pathways in the Lagoon at Lord Howe Island. Such a study would be expected to cost about $150,000, depending on the number of placement sites and colours employed, and number of sampling events.

The study would be most valuable if a significant coastal storm event occurred during the tracer deployment. Given that the tracer does not decay, it would be possible to extend the duration of a tracing study as required to capture such an event.

12.3 Relevance of Proposed Immediate Management Actions for Managing Risks at Pinetrees Boatshed

If the management actions for Lagoon Beach (described in Section 12.2) were implemented, this would have the following effects on the Pinetrees boatshed area:

- Action 1 (discontinue beach scraping): this would also be beneficial (cross-shore beach scraping should be discontinued in all areas).

- Action 2 (develop emergency action plan): it would be feasible from a coastal engineering perspective for the Pinetrees owner to undertake emergency rock protection of the boatshed, although it is noted that the deck area may be undermined before any protection could be implemented. However, if this was undertaken, pedestrian access from the boatshed area to and from the beach would be restricted. The Pinetrees owner would need to seek Owner's Consent from the Board if such works were considered, and a Development Application would need to be submitted.

- Action 3 (alongshore sand relocation) and Action 4 (beach nourishment): placing sand from alongshore sand relocation or beach nourishment in the vicinity of Pinetrees boatshed would be beneficial in reducing coastline hazard risks to the boatshed. The Pinetrees owner has contributed to some of the costs of beach scraping carried out by the Board in this area in the past.

- Action 5 (beach profile surveys) and Action 6 (sand tracing study): the beach profile surveys and sand tracing study would assist in the understanding of coastal processes in the vicinity of Pinetrees boatshed.

13. POTENTIAL FUTURE MANAGEMENT ACTION OPTIONS

13.1 Preamble

A number of potential future long term action options for managing the risk of undermining of Lagoon Road and Pinetrees Boatshed were assessed, as discussed in Section 13.2 and Section 13.3 respectively. Potential future action options for managing other coastline issues at Lord Howe Island are discussed in Section 13.4.

It is expected that these options would be considered and further assessed as part of any future Coastal Zone Management Plan (CZMP) at Lord Howe Island.

13.2 Potential Future Action Options at Lagoon Road

13.2.1 Moving Road and Underground Cables Landward

If it is found that the risk of damage to Lagoon Road and adjacent cables cannot be managed through alongshore sand relocation and/or beach nourishment (eg if sufficient suitable sand sources cannot be accessed), there could be consideration given to moving Lagoon Road landward. A conceptual layout of a potential relocated road position is provided in Figure 46, assuming adoption of a minimum 20m distance from the 2011 erosion escarpment position (as derived from photogrammetric data) to the relocated road. The total area of relocated road as depicted is about 350m^2, over a length of about 70m.

Based on advice from the Board's Administration, the cost of this option would be in the order of $350,000 (using Board staff and equipment)[72]. A disadvantage of this option (in isolation) would be that there would be no restriction on continuing recession at the southern end of Lagoon Beach. That is, there would be expected to be continuing loss of habitat of the Lord Howe Island skink and wedge-tailed shearwater, and no reduction in coastline hazard risk to Pinetrees boatshed. The relocated road and cables may also be at risk of undermining again in the future if recession continues.

Advantages of the option include:

- relatively low environmental impact;
- minimal visual impact;
- no impact on coastal processes; and
- it provides more time to assess if recession will continue north of the bag wall.

[72] Haskoning Australia has not independently assessed this costing, although it is noted that a 6m wide road (with concrete kerbs) of the same extent (70m length) as the proposed relocation would cost about $25,000 in Sydney based on the *Rawlinsons Australian Construction Handbook 2014*.

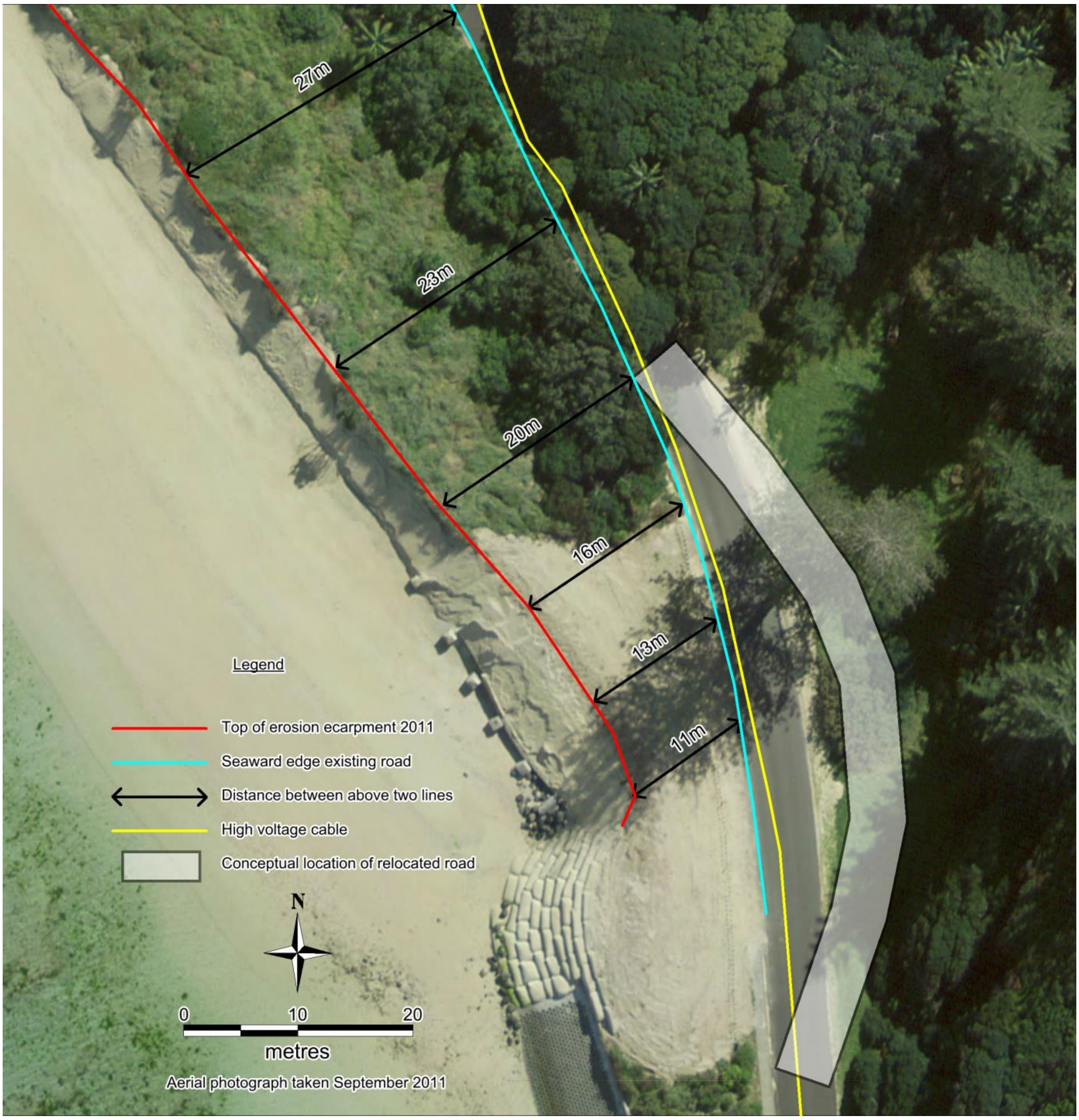

Figure 46: Conceptual layout of potential relocated Lagoon Road in vicinity of bag wall

13.2.2 Seawall/Revetment

If it is found that the risk of damage to Lagoon Road cannot be managed through alongshore sand relocation and beach nourishment, and relocation of the road and cables is not considered to be appropriate (for example if it is considered to be more important to protect the currently receding dunal area due to its important habitat, or a suitable route cannot be found), then there may be consideration of a seawall/revetment extending north of the Seabee revetment and bag wall.

The seawall/revetment could be constructed from rock or sand filled geotextile containers (bags), as sloping structures like the existing runway revetment and bag wall. Other construction materials are also possible, such as concrete Seabees (as have been used previously at Lagoon Beach).

The advantage of the seawall/revetment option is that if it was designed and constructed appropriately including coastal engineering input, it would effectively limit further erosion and recession, reducing risk to landward assets and habitat to acceptable levels. However, there are a number of disadvantages to this option:

- visual impact;
- potentially transferring erosion/recession further north; and
- potential loss of beach width adjacent to seawall/revetment if recession continues.

Planning approvals would need to be in place for these works if they are to be implemented, and they would be subject to environmental assessment (see Section 14).

Rock has advantages over bags in having well established design guidelines, longer design life, better tolerance to events exceeding the design event, and faster and simpler construction. Rock is potentially available locally (eg from Little Island), but may become prohibitively expensive to use if it had to be imported to Lord Howe Island. For a bag wall, sand would have to be sourced from accreting areas for filling the bags, as it would not be appropriate to use sand from receding areas of Lagoon Beach given the potential for this to exacerbate recession.

If the most at risk area immediately north of the bag wall was to be protected (over a 30m length), costs would be in the order of $300,000, assuming local rock or sand was used as applicable (but see Section 1.3 with regard to the limitations of this cost estimate)[73]. Costs would be far greater if rock or sand had to be imported from the mainland.

13.2.3 Potential Options Requiring Additional Investigations (if Considered Warranted)

Groyne

There may be consideration of the construction of a (shore-normal) groyne north of the eroding area located north of the bag wall, in order to attempt to hold sand on the beach (to the south of the groyne) and therefore reduce erosion risks. This could be used in conjunction with beach nourishment. However, additional investigations (eg sediment tracing) would be necessary to determine the likely effectiveness before proceeding further (in particular, the relative significance of longshore sediment transport processes). A groyne placed south of Pinetrees boatshed may also adversely impact on coastline hazards at the boatshed due to downdrift erosion.

Planning approvals would need to be in place for these works if they are to be implemented, and they would be subject to environmental assessment (see Section 14).

Offshore Breakwater

There may also be consideration of the construction of a breakwater located offshore of the eroding area north of the bag wall. If effective, this would reduce erosion risk while also allowing beach width to remain. However, this option would be relatively costly (more expensive than a seawall/revetment),

[73] This estimate was based on a rate of $10,000/m. A recent detailed cost estimate by Haskoning Australia for a bag wall on the NSW mainland open coast was similar (although it was assumed that a commercial sand source would be used in this case at a cost of $40/m^3), and Haskoning Australia has been involved in numerous NSW mainland open coast rock protective works with as-built costs between $10,000 and $20,000/m.

and would have to be constructed well above mean sea level to be effective during higher tides and during higher water levels when storms occur. This would have associated visual and environmental impacts, as well as potential impact on adjacent coastal processes. Again, additional investigations (eg sediment tracing) would be necessary to determine likely effectiveness before proceeding further.

Planning approvals would need to be in place for these works if they are to be implemented, and they would be subject to environmental assessment (see Section 14).

13.3 Potential Future Action Options at Pinetrees Boatshed

The boatshed could be constructed on piles to reduce the risk of damage from undermining, which could allow the boatshed to remain in its present position at acceptable risk. However, it would be difficult to retrofit piles to the existing structure, and access to the beach from the boatshed would be problematic if erosion/recession continues under the structure (due to the height of the erosion escarpment).

It may also be possible to relocate the boatshed, moving it further landward to reduce the risk of it being undermined. If this was considered, there may also be the option of constructing it on piles to further reduce risk.

It is recognised that the structure may need to be rebuilt if relocation was undertaken, as it may be difficult to relocate intact. Depending on the distance moved, the structure may eventually be at unacceptable risk again in the future (unless constructed on piles, or made relocatable). If the structure was relocated from its current position, some views from near the structure may be lost (as well as proximity to the beach), that may detract from the visitor experience.

An engineered seawall/revetment could be constructed seaward of Pinetrees boatshed, say over a length of about 50m (including extending landward at the ends, to reduce the risk of flanking erosion). Such a structure would reduce the coastline hazard risk to the boatshed to acceptable levels. However, there would be visual impacts if this option was adopted, as well as potential 'end effects' on adjacent areas. Engineered beach access (eg stairs) would be also be required to enable access from the boatshed to the beach.

If there was consideration of the construction of a continuous seawall/revetment extending from the bag wall to Pinetrees boatshed (140m length), costs may be in the order of $1.4 million (but see Section 1.3 with regard to the limitations of this cost estimate)[74]. There would also be visual impacts, and a potential transferring of erosion further north. There would also be potential loss of beach width adjacent to the seawall/revetment if erosion/recession continued. Engineered beach access (eg stairs) would be required to enable access from the seawall/revetment to the beach.

13.4 Other Relevant Management Actions

13.4.1 Maintain Reef Health

The coral reef on the western side of Lord Howe Island is critical to maintaining beaches adjacent to the Lagoon and the Lagoon itself, given that the reef dissipates a large proportion of incoming offshore swell wave energy. The Board and Marine Estate Management Authority should continue supporting

[74] Also see Footnote 73 on page 70.

research into reef health and implementing measures to improve reef health, such as implementing the onsite wastewater management strategy which has been developed (which includes replacing septic tanks and upgrading secondary treatment systems).

Key long term issues with reef health and structure are whether the reef elevation will increase at the same rate as sea level rise, how the reef may be affected by acidification, and how any changes in the East Australian Current and El Nino / La Nina patterns will affect reef health. Research into how to best adapt the reef to withstand these effects is recommended.

13.4.2 Monitor Sallywood Swamp Forests

As discussed in Section 11, it is recommended that:

- the health of the Sallywood Swamp Forests at Lord Howe Island are monitored in relation to inundation events, to determine if creek opening trigger levels need to be adopted to enhance its viability; and
- a natural entrance opening regime is maintained, unless adoption of a manual water level trigger for opening is required in order to enhance the Sallywood Swamp Forests, or to protect infrastructure (but only where this would not adversely impact on the Sallywood Swamp Forests).

13.4.3 Maintain Dune Vegetation

A healthy coverage of dune vegetation acts to trap windblown sand and prevent blow outs, and hence assists in retaining (and enhancing) available sand volumes on a beach to meet storm demand. This is demonstrated at Blinky Beach (for example), with the dunes there naturally growing in height and volume over time. It is thus recommended that dunal vegetation coverage is maintained at the landward edge of the sandy beaches at Lord Howe Island.

There is a view from some of the Board's Administration that shallow rooted grass species such as Buffalo and Kikuyu lead to greater dune slumping (less binding of sand) in erosion events compared to deeper rooted species. However, it must be recognised that vegetation alone would not resist storm erosion such as being experienced north of the bag wall at Lagoon Beach.

The Board's Administration would prefer the use of the following native species for dunal vegetation: Beach Spinifex (*Spinifex hirsutus*), Knobby Club Rush (*Isolepis nodosa*), Beach Sunflower or Sea Daisy (*Melanthera biflora*), Saltwater Couch (*Sporabolis virginicus*), Pigface (*Carpobrotus glaucescens*), Scented Fan Flower (*Scaevola calendulacea*), Beach Bean or Beach Morning Glory (*Ipomoea pes-caprae* ssp *Brasiliensis*), Beach Pea or Sea Bean (*Vigna marina*), Bully Bush (*Cassinia tenuifolia*), and Berrywood (*Ochrosia elliptica*). The Board's Administration considers that dunal vegetation areas comprising Buffalo or Kikuyu grasses should be progressively rehabilitated with the above listed species.

13.4.4 Signage at Base of Cliff Areas

In the Brief, it was noted that cliff instability had been occurring at Neds Beach, Middle Beach and Signal Point. The observations below were based on an August 2012 site visit. Note that at all three of these sites there was signage (denoted as a "warning sign" below) on which it was stated "Warning, Falling Rocks".

At Neds Beach, the area of historical instability is located at the southern end of the beach. At the time of the site visit, there was a single warning sign located just north of this cliff area (Figure 47). There were some boulders and finer material deposited at the base of the cliff at several locations (known as scree or talus), see Figure 48, but there was no evidence of widespread instability. Immediately north of the area of minor instability (or weathering), the lower portion of the cliff face had some graffiti etched into the cliff face (behind the warning sign in Figure 47).

At Middle Beach, there was evidence of occasional blocks having toppled from the cliff, with a few blocks located adjacent to the base of the cliff. There was a single warning sign located near the alongshore centre of the beach. At the northern end of Middle Beach, there was evidence of a relatively recent minor cliff "failure", with some small boulders and mainly cobble and finer material deposited along and at the base of the slope as scree/talus, see Figure 49.

At Signal Point, there was evidence of occasional block toppling, with some boulders located at the base of the cliff. Warning signs were noted at the bases of the northern and southern ends of the cliff.

Figure 47: Cliff area at southern end of Neds Beach, with warning sign evident

Figure 48: Area of some cliff instability at southern end of Neds Beach

Figure 49: Cliff “failure” at northern end of Middle Beach, 28 August 2012

The cliff “failures” at Neds Beach, Middle Beach and Signal Point are considered to be mostly related to weathering of the calcarenite, which as noted in Section 4.1 is extremely susceptible to weathering.

To manage the risk to life from falling rocks at these locations it is recommended that:

- there is community education as to possibility of rock falls and the potential danger of being in proximity to the base of these cliffs;
- warning signage includes the warning “do not enter the area near the cliff base” or the like (the existing signage warns of a danger but does not advise an action);
- an additional sign (including the above warning) is installed adjacent to the area depicted in Figure 48 at Neds Beach; and
- additional signage (including the above warning) is installed at the northern and southern entry stairways to Middle Beach.

It is understood that the company Coffey has completed a verbal assessment of slope stability at Neds Beach, Middle Beach and Signal Point based on visual inspection only. Haskoning Australia was not provided with any information deriving from this assessment.

14. APPROVALS REQUIRED FOR POTENTIAL WORKS

14.1 Works Undertaken by or on Behalf of Board

As noted in Section 12.2.3, it is recommended that the Board develops an Emergency Action Plan for placement of rock protective works to protect Lagoon Road and adjacent underground cables at the southern end of Lagoon Beach. In Section 12.2.4 and 12.2.5 respectively, it was recommended that alongshore sand relocation and beach nourishment were adopted as actions.

In Section 13.2.2, it was noted that there may be future consideration of the construction of a seawall/revetment at the southern end of Lagoon Beach. In Section 13.2.3, other potential options requiring additional investigations (if considered warranted) were listed, namely a groyne and offshore breakwater.

Based on Clause 10(1)(e) of the *Lord Howe Island Local Environmental Plan 2010*, “nothing in this Plan prohibits, requires development consent for, or otherwise restricts the carrying out of environmental protection works by or on behalf of the Board”. Based on Clause 10(3), “environmental protection works means any works associated with the rehabilitation of land towards its natural state or any work to protect land from environmental degradation, and includes vegetation restoration works, wetland protection works, erosion protection works, dune restoration works and the like”. All of the above listed works (placement of emergency rock protective works, alongshore sand relocation, beach nourishment, seawall/revetment, groyne, and offshore breakwater) would be expected to fall within that definition, namely as “erosion protection works”.

Given that development consent would not be required for the works listed above, Part 5 of the *Environmental Planning and Assessment Act 1979* would apply to the works. Completion of an environmental assessment would be required. The environmental assessment would comprise a Review of Environmental Factors (REF), or if significant impacts were expected an Environmental Impact Statement (EIS) would need to be prepared[75].

The factors to be taken into account when consideration is being given to the likely impact of any of these works on the environment are listed in Clause 228 of the *Environmental Planning and Assessment Regulation 2000*. In addition to this, the following legislation would need to be considered prior to the Board carrying out any works:

- Section 5A of the *Environmental Planning and Assessment Act 1979*;
- NSW *Marine Parks Act 1997*;
- NSW *National Parks and Wildlife Act 1974*;
- NSW *Threatened Species Conservation Act 1995*;
- NSW *Coastal Protection Act 1979*; and
- Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*.

[75] An REF has no statutory basis, but a determining authority usually decides (as part of standard practice in NSW) whether to require a full EIS by considering a preliminary environmental assessment in the form of an REF.

14.2 Works Undertaken by Owner of Pinetrees Boatshed

Should the Permissive Occupancy holders at Pinetrees boatshed want to install protective works, they would need to seek Owner's Consent from the Board[76], and a Development Application would need to be submitted.

In assessing likely impacts, the Board would need to ensure that the proposal:

- was permissible and an appropriate use of the site according to its zoning;
- complied with the provisions of the *Environmental Planning and Assessment Act 1979*;
- complied with the provisions of the *Lord Howe Island Local Environmental Plan 2010* and any other relevant planning controls for the site;
- had no detrimental environmental impacts upon the locality; and
- had no adverse impact upon adjacent and neighbouring properties (Lord Howe Island Board, 2014).

The Pinetrees boatshed is within a "foreshore area" as defined in the *Lord Howe Island Local Environmental Plan 2010* (Figure 50). The foreshore area means the land between the Foreshore Building Line and the mean high water mark.

Based on Clause 35(2) of the *Lord Howe Island Local Environmental Plan 2010*, development on the foreshore area is prohibited unless:

(a) the proposed development is in the public interest and does not significantly reduce public access to the foreshore, and
(b) the bulk and scale of the proposed development will not detract from the visual amenity of the foreshore area, and
(c) the proposed development addresses any need to restore lost or disturbed plants that are native to the Island, particularly if restoring those plants may enhance visual amenity, and
(d) there is a demonstrated Island community-based, or marine-based, business need for it, and
(e) the proposed development will not be adversely affected by, or adversely affect, coastal processes, and
(f) in the case of proposed development involving the erection of a structure—the purpose of that structure could not practicably be fulfilled by an existing structure, and
(g) in the case of development proposed to be carried out on land that is also within Zone 9 Marine Park—the proposed development is not inconsistent with any advice about the development that is provided to the consent authority by the Marine Parks Authority.

Therefore, any protective works proposed by the owner of Pinetrees boatshed would need to comply with the above Clauses.

Also, it would be necessary for the Board to ensure that the Pinetrees owner was responsible for continuing maintenance of the works, and removal of the works if required (if they failed or caused significant adverse impacts on adjacent areas), and/or maintenance of beach amenity seaward of the works, as appropriate.

[76] The Minister has authorised that the Board's Chief Executive Officer can grant owners consent to the lodgement of a development application if the value of the development does not exceed $2,000,000, the proposal complies with the current Planning instrument, and the development application does not relate to the subdivision of land or creation of a new residential dwelling.

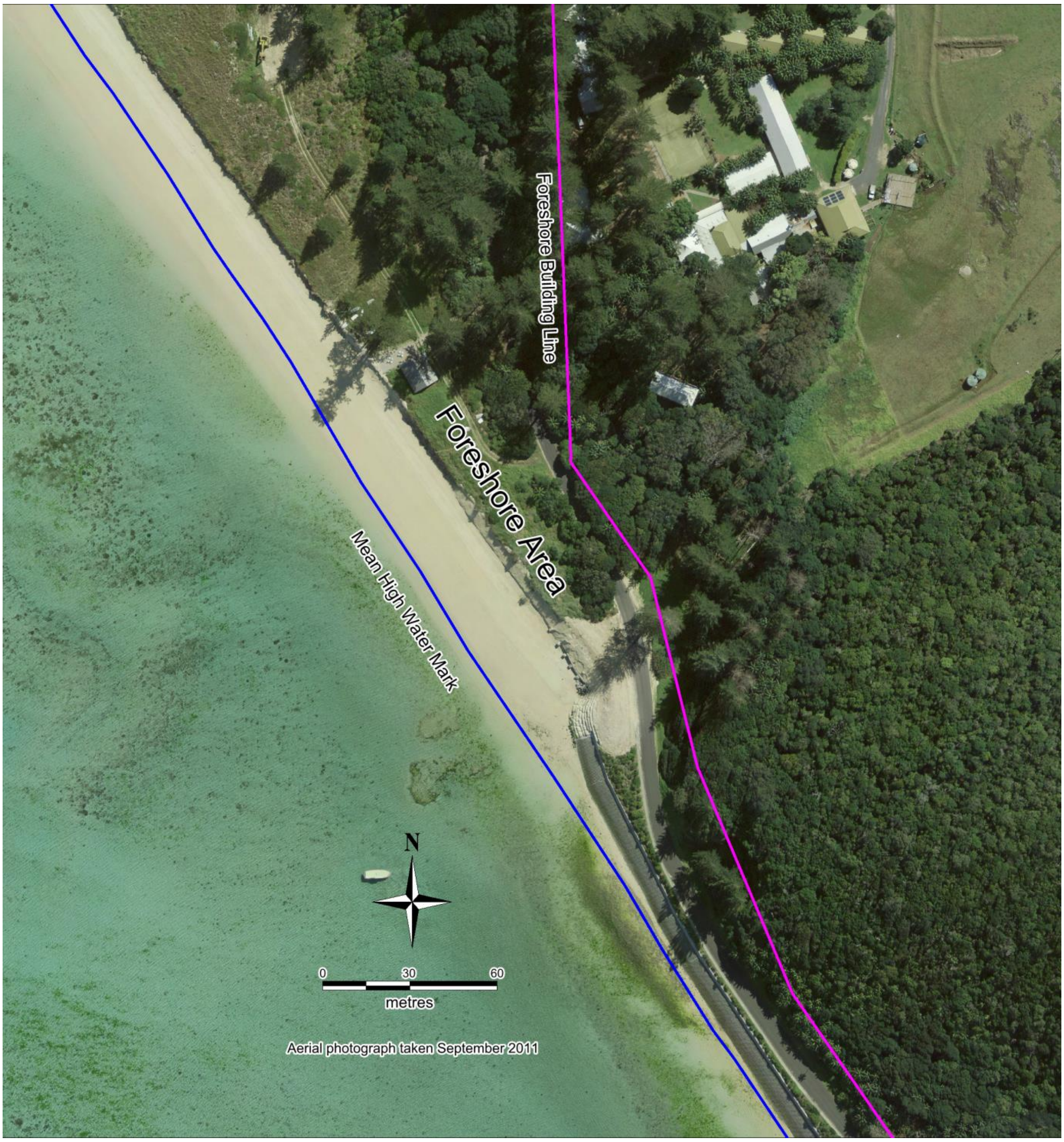

Figure 50: Foreshore area in vicinity of Pinetrees boatshed

15. CONCLUSIONS

Haskoning Australia Pty Ltd was engaged by the Lord Howe Island Board to complete a Coastal Hazard Definition and Coastal Management Study for Lord Howe Island, as has been set out herein. There are a number of coastline management issues at Lord Howe Island, in particular erosion/recession threatening Lagoon Road (and underground cables) at Lagoon Beach near Windy Point.

Erosion of the Windy Point area has been documented for some time. The road at Windy Point was undermined and rebuilt about six times prior to 1965, and also in 1985. Protective works (such as 44 gallon drums and gabions) were placed at Windy Point in the late 1980's in an attempt to limit this erosion. Ongoing coastal storms over the next few years, and the continuing risk of damage to Lagoon Road, led to the construction of a Seabee revetment at Windy Point in 1999.

An airport was opened at Lord Howe Island in 1974, which included a 70m protrusion of the runway into the Lagoon, protected by a rock revetment. Although some consider that this runway protrusion interrupted longshore sediment transport and caused erosion/recession at Windy Point, it is evident that the area was experiencing erosion prior to the runway construction.

After construction of the Seabee revetment in 1999, erosion began to be experienced to its north, ultimately leading to construction of a sand-filled geotextile container (bag) wall in the eroding area in 2011. However, erosion has continued to the north of the bag wall since that time.

The most southerly coral reef in the world is located at Lord Howe Island, with an average crest level of 1.0m AHD, which is 0.2m below mean sea level in the Lagoon (unlike the Australian mainland, AHD at Lord Howe Island is not equivalent to mean sea level, but is at a level of extreme low tide known as Chart Datum). However, the elevation of reef crests is variable, and wave energy is likely to be focussed on the Windy Point area due to lower reef crests directly offshore from Windy Point.

The Lagoon adjacent to the reef has an average depth of about 2m, but with a much deeper area near Comets Hole, which is likely to act as a sink for sediment moving between the reef crest and shoreline. It has been estimated that sediment began to accumulate over basalt bedrock in the Lagoon about 4,600 years ago, with greater sediment availability after 2,900 years ago as sediment filled sinks in the Lagoon floor and reached a shallow enough depth to be reworked by waves. Increasing westerly wind strength from about 700 years ago, combined with falling sea levels and this lagoon infilling, facilitated increased sediment movement from the reef crest and the Lagoon bed to the western shore of Lord Howe Island. This caused rapid development of beaches about 600 years ago. Sediment may still be moving landward across the Lagoon bed and adding to subaerial beach sediments.

Rates of change of volume per year were determined along Lagoon Beach and Cobbys Beach, based on review of 5 dates of aerial photography and photogrammetric data from 1965 to 2011. It was evident that most of the length of beaches along the Lagoon at Lord Howe Island have been growing in sand volume or moving seaward (prograding). The only two areas reducing in volume or moving landward (receding) are located immediately north and south of the runway revetment, Seabee revetment, and bag wall structures.

Further investigation of the sources and transport direction of sediment in the wider Lagoon would be warranted to inform a longer term understanding of coastal processes and to inform the design of any future beach nourishment campaigns or other works. A preliminary conceptual model of sediment transport processes that was an attempt to document the observed beach changes and was consistent with observed circulation patterns was developed.

Immediate (as of 2011), 2050 and 2100 Coastline Hazard Lines (defined at the landward edge of the Zone of Slope Adjustment) were delineated herein. The key assets at immediate risk of damage at Lagoon Beach and Cobbys Beach are Pinetrees boatshed and Lagoon Road near the bag wall. Considering 2050 and 2100 timeframes, the boatsheds at the northern end of Lagoon Beach begin to become at risk, as does the Aquatic Club. Without the protection of the Seabee revetment and rock revetment, Lagoon Road and the runway would be at immediate risk of damage, indicating the importance of maintaining these structures.

Immediate management actions to reduce the risk of undermining at Lagoon Road (for which investigations should be commenced or actions undertaken now) were developed as follows:

- discontinue beach scraping;
- develop Emergency Action Plan;
- alongshore sand relocation;
- beach nourishment;
- beach profile surveys; and
- a sand tracing study.

A number of potential future long term action options for managing the risk of undermining of Lagoon Road were also assessed, including moving Lagoon Road and nearby underground cables landward; and construction of a seawall/revetment.

Entrance management of Old Settlement Creek, Cobbys Creek and Soldiers Creek was also considered, particularly in terms of managing Sallywood Swamp Forest (a Critically Endangered Ecological Community) and flooding. Where possible, it was recommended that a natural entrance opening regime be maintained. The key effect of entrance openings in terms of reducing the health of the Sallywood Swamp Forest is the ingress of saline water. Saline intrusion could be reduced by:

- mechanically closing off an entrance immediately after a breakout event; and/or
- maintaining the beach berm level seaward of a creek at a higher level; and/or
- mechanically opening an entrance (if that was required) on a low to rising tide.

All of the above actions would be counterproductive to any requirements to manage an entrance to reduce inundation (flooding) levels to protect infrastructure.

There is a substantial delta of sand formed within the Lagoon seaward of Old Settlement Creek. There may be consideration of using this delta as a source of sand for beach nourishment, subject to detailed assessment. A smaller delta is also present at Cobbys Creek.

Other relevant management actions were developed, namely:

- maintain reef health;
- monitor Sallywood Swamp Forests;
- maintain dune vegetation; and
- install signage at the base of cliff areas.

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APPENDIX A
SITE VISIT OBSERVATIONS AND DISCUSSIONS

CONTENTS

A1. BACKGROUND

Peter Horton and Gary Blumberg of Haskoning Australia visited Lord Howe Island from 27 August to 1 September 2012 inclusive.

In this Appendix, photographs and notes from site observations, and notes from discussions with Island residents and Board staff, are presented. The Appendix is arranged under geographical headings.

A2. OBSERVATIONS AND DISCUSSIONS

A2.1 Lagoon Beach

A series of photographs taken from south to north along Lagoon Beach is provided in Figure A1 to Figure A7. Note that the mounded sand visible seaward of the erosion escarpment in Figure A4 and Figure A5 had recently been mechanically placed (it had been sourced by beach scraping from about 100m to 300m north at around the low tide level).

Figure A1: Southern end of Lagoon Beach at junction between airport revetment and Seabee wall, looking south

Figure A2: Looking north along Seabee wall at southern end of Lagoon Beach

Figure A3: Northern end of Seabee wall at Lagoon Beach, looking north

Figure A4: Sand-filled geotextile containers north of Seabee wall at Lagoon Beach

Figure A5: View of beach erosion escarpment north of Pinetrees boatshed

Figure A6: View south along Lagoon Beach from near access track opposite Board Administration

Figure A7: View north along Lagoon Beach from near from near access track opposite Board Administration

A2.2 Cobbys Beach

General views of Cobbys Beach are provided in Figure A8 to Figure A10.

Figure A8: View to north along Cobbys Beach from near the southern end

Figure A9: View to south along Cobbys Beach from near the centre of beach

Figure A10: View to south along Cobbys Beach from northern end (near airport revetment)

A2.3 Blinky Beach

A general view of Blinky Beach is provided in Figure A11.

Figure A11: View to south at Blinky Beach from crest of dune at accessway

A2.4 Neds Beach

General views of Neds Beach (moving north to south) are provided in Figure A12 to Figure A14.

Figure A12: Northern end of Neds Beach, looking north

Figure A13: Central view of Neds Beach, looking north

Figure A14: Southern end of Neds Beach, looking south

A2.5 Middle Beach

A general view of Middle Beach is provided in Figure A15.

Figure A15: General view of Middle Beach

APPENDIX B

REVIEW OF AERIAL PHOTOGRAPHY AND PHOTOGRAMMETRIC DATA

CONTENTS

B1. BACKGROUND

Aerial photography and photogrammetric data capturing beach conditions along Lagoon Beach and Cobbys Beach (in 1965, 1975, 1984, 2001 and 2011) has been reviewed. The photogrammetric data was provided by the Office of Environment and Heritage, NSW Government.

The photogrammetric data comprised 52 shore-normal beach profiles (numbered from 1 in the north to 52 in the south) arranged into 6 blocks (with a block being a set of parallel profiles), with an alongshore profile spacing of 50m within each block. The location of the profiles is shown in Figure B1 (for the Lagoon Beach and Seabee seawall area) and Figure B2 (for the runway revetment area and Cobbys Beach).

The photogrammetric data was analysed particularly to determine long term beach recession rates. To assess long term recession rates, changes in volume and in the position of various contour levels were determined at each profile over time. This procedure is often denoted as Profile Area Volume (PAV) analysis. Volumes were determined using scripts developed by Haskoning Australia in the software package MATLAB[1].

For the study reported herein, volumes above 0m AHD are given. The volume above 0m AHD was used as it was defined in many profiles without necessity for extrapolation of the profiles seaward, or only required extrapolation over a relatively short distance[2]. However, note that 0m AHD at Lord Howe Island is not equal to mean sea level as on the NSW mainland, but is 1.2m below mean sea level in the Lagoon.

Profiles were generally extrapolated (if required) by continuing the profiles at the same average slope for the block and year as measured between the last two most seaward points in the profiles (generally near 0m AHD). This slope was typically around 1:10 (vertical:horizontal).

In the analysis, the complete profiles (extending to the landward limit) were considered, as well as landward truncations to both a position in the vicinity of the sand/vegetation interface as visible in 2011 aerial photography, and also 10m and 20m further landward. Applying a landward truncation is relevant, as changes to profiles further than 10m landward of the 2011 sand/vegetation interface can mostly be considered to be related to anthropogenic processes such as levelling for development, rather than natural coastal processes.

In addition to volumes, the position of particular elevations (namely 0m, 1m, 2m and 3m AHD) was determined over time.

For each of the profiles, the rate of change of volume above 0m AHD, and the rate of change of position of the particular elevation, was determined. The rates were derived by linear regression, that is by determining the line of best fit (least squares error) in each case[3]. The advantage of using linear regression, rather than simple differences between the first and last dates of photography, is that errors in predicted rates due to variations in beach states are likely to have been minimised. Rates of change were determined for the entire analysis period (1965 to 2011), as well as investigation being undertaken of changes between each date.

[1] MATLAB is a high-level technical computing language and interactive environment for algorithm development, data visualisation, data analysis, and numerical computation.
[2] For all data, 73% of profiles extended below 0.5m AHD, and 100% extended below 1m AHD.
[3] This does not imply that there were uniform rates of volume or positional change between dates of photography.

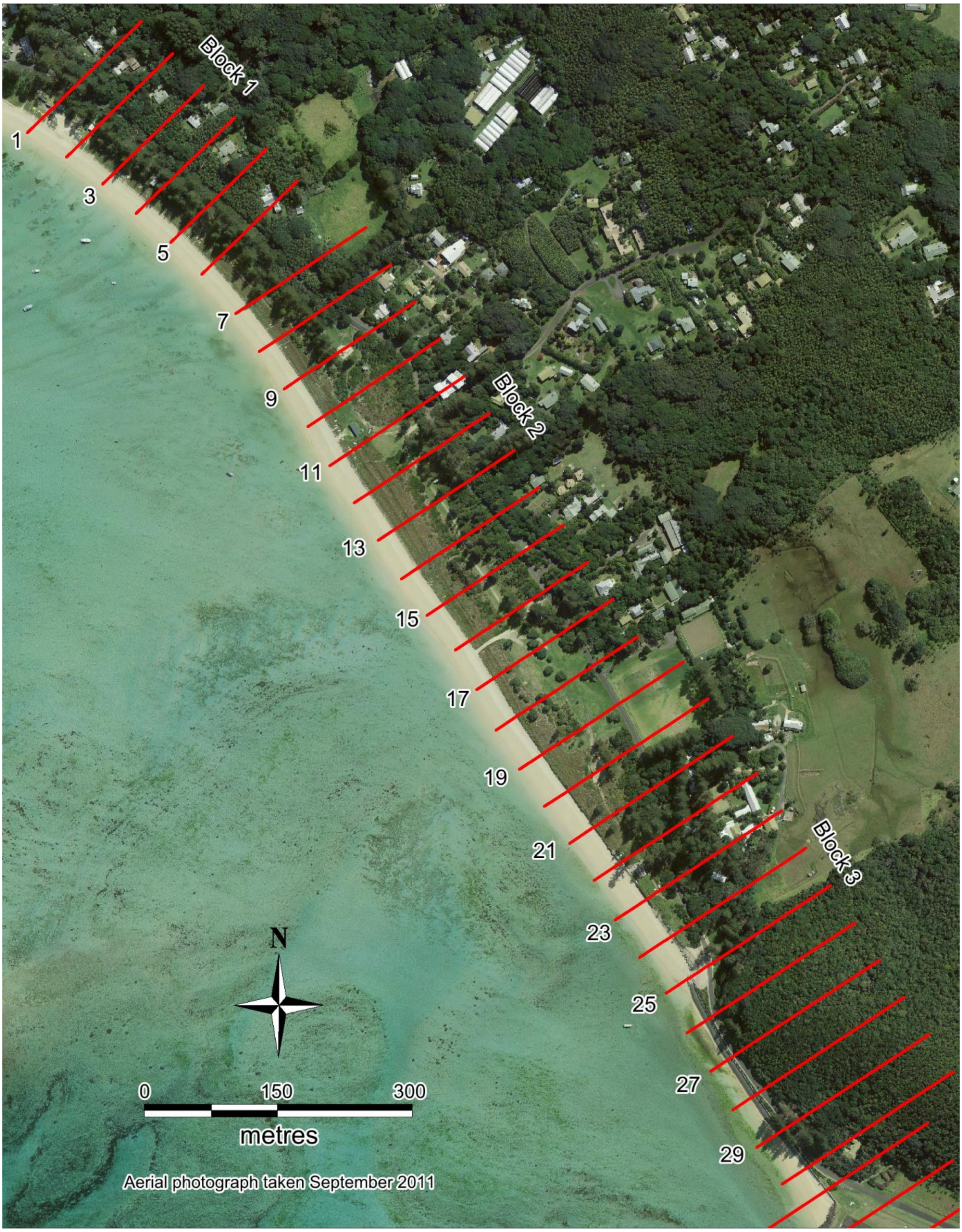

Figure B1: Arrangement of photogrammetric profiles at Lagoon Beach and along Seabee seawall

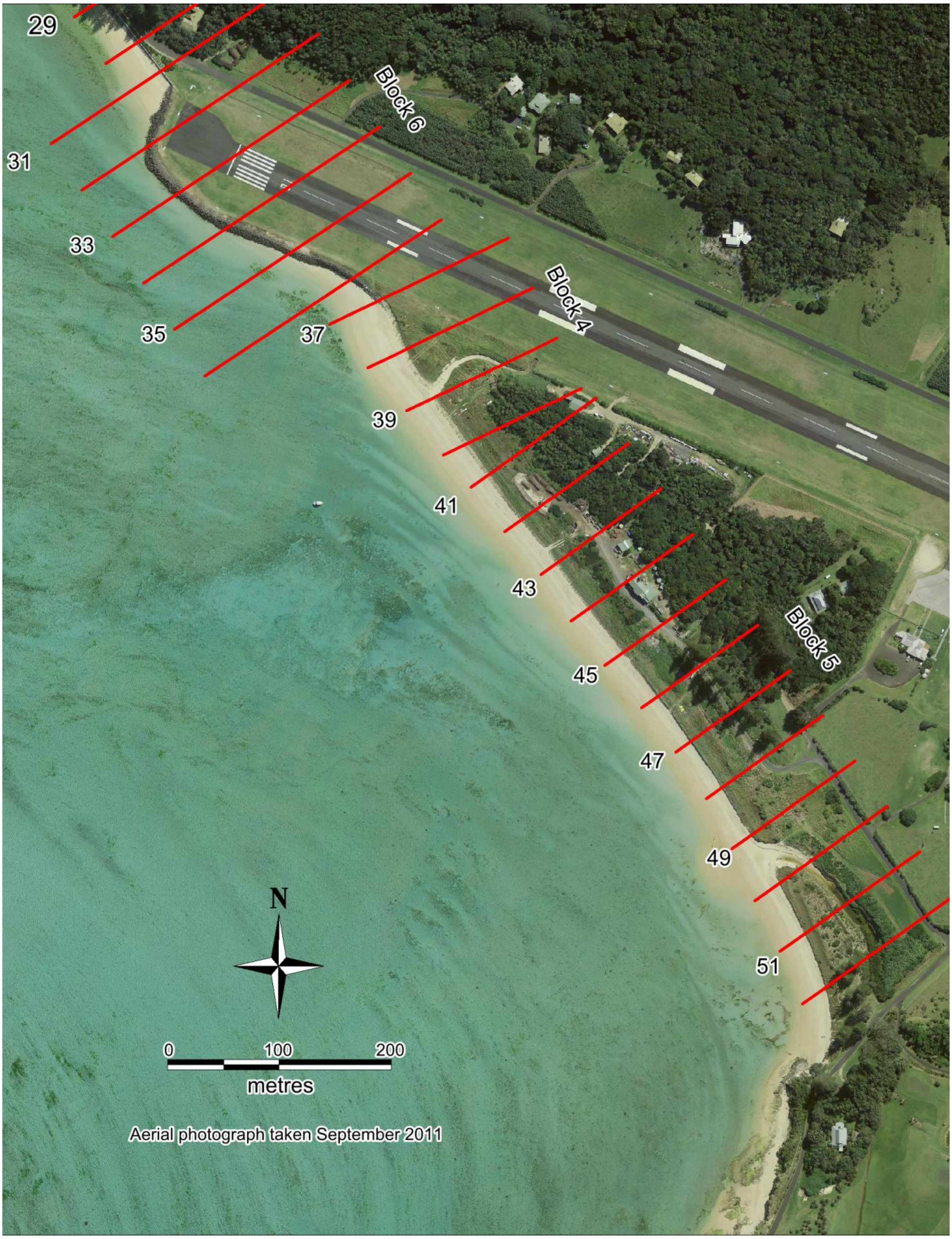

Figure B2: Arrangement of photogrammetric profiles along runway revetment and at Cobbys Beach

B2. DEFINITIONS

The following terms have been adopted herein to describe the short term and long term movements of beaches in the study area:

- ***erosion***: the offshore movement of sand from the subaerial[4] beach during storms, that is a short term loss of subaerial beach volume and short term landward shift of the beach face[5];
- ***accretion***: the opposite of erosion, typically when sand that moved offshore under storm conditions returns to the subaerial beach under milder conditions, increasing the subaerial beach volume and translating the beach face seaward;
- ***recession***: a long term progressive (on average) reduction in subaerial beach volume and long term landward shift of the beach face; and
- ***progradation***: the opposite of recession, a long term progressive (on average) increase in subaerial beach volume and long term seaward shift of the beach face.

There is some overlap in these terms, for example the process of progradation can be through an excess movement of sand onshore that is typically associated with accretion. Also, when looking at beach changes between various dates, there can be a number of short term cycles of erosion and accretion associated with storms as well as alongshore and windblown movements of sand occurring over this period, leading to recession or progradation. Any beach change over a period of years has been considered as recession or progradation (as the case may be) herein.

In interpreting beach changes over time, it is important to distinguish between natural processes and anthropogenic effects, where possible. For example, about 8,000m^3 of sand (sourced from Blinky Beach) was placed along the position of the current Seabee seawall in 1991.

[4] "Subaerial" literally means "under the air", and this case refers to beach changes above the waterline, as opposed to "subaqueous" changes underwater. Large waves combined with elevated water levels typically remove sand off the upper (subaerial) beach profile and transport this sand offshore.
[5] This landward shift can be throughout the entire subaerial beach profile, such as landward movement of the shoreline (mean sea level position) and landward movement of an erosion escarpment (dune face).

B3. VOLUME CHANGES AND CONTOUR MOVEMENTS

The rate of change of volume above 0m AHD, and the rate of change of the position of the 1m and 2m AHD contours (both for the 1965 to 2011 period), are depicted in Figure B3 (raw data) and Figure B4 (smoothed data using a running average with a window width of 5[6]) along Lagoon Beach and Cobbys Beach.

For Figure B3 and Figure B4 note that:

- the section covered by the runway revetment was not included in the analysis as this is an anthropogenic reclamation, and being a terminal structure there have not been any significant changes in the subaerial shoreline in this area from 1975 to 2011;
- contour changes at 0m and 3m AHD were generally similar to those shown for 1m and 2m AHD, but were not depicted for clarity; and
- profiles were truncated at 10m landward of the sand/vegetation interface visible in 2011 aerial photography (forming a landward limit to calculations); a comparison of volume calculations using a landward limit at the 2011 sand/vegetation interface is provided in Figure B5.

It is evident that the analysed patterns of volume and contour change were very similar along these beaches. Most areas along Lagoon Beach and Cobbys Beach showed evidence of progradation, but with recession south of the access track opposite the Board Administration office at Lagoon Beach extending to the runway revetment, and recession also immediately south of the runway revetment at Cobbys Beach.

The difference in the volumetric rates for the two landward limit options utilised in Figure B5 indicates that:

- where progradation has been occurring this has been over the full beach profile including the vegetated dunal area (that is, both the sandy beach and vegetated area has been prograding)[7]; and
- where recession has been occurring this has only been seaward of the erosion escarpment (that is, the vegetated area landward of the escarpment has remained stable while the beach area seaward has receded)[8].

Analysis was also undertaken for a landward profile limit 20m landward of the sand/vegetation interface (except at structures and the northern Lagoon Beach headland near Signal Point, where it is not relevant to extend the limit landward of the fixed structure/cliff). The same pattern of increasing progradation in prograding areas and similar recession in receding areas was generally observed.

[6] This means that data was averaged using the data point, two points prior and two points following (5 in total).
[7] As evident with the volume rates for the more landward limit being larger (by about a factor of 2) where progradation has occurred.
[8] As evident with the volume rates for each landward limit being similar where recession has occurred. This makes physical sense as in some receding areas the dunal area has a fixed structure (namely along the Seabee seawall and at the southern end of the runway revetment), and in other areas the erosion escarpment has been relatively high such that windblown sand may be unable to be transported over the crest of the escarpment into the vegetated area (namely at the southern end of Lagoon Beach).

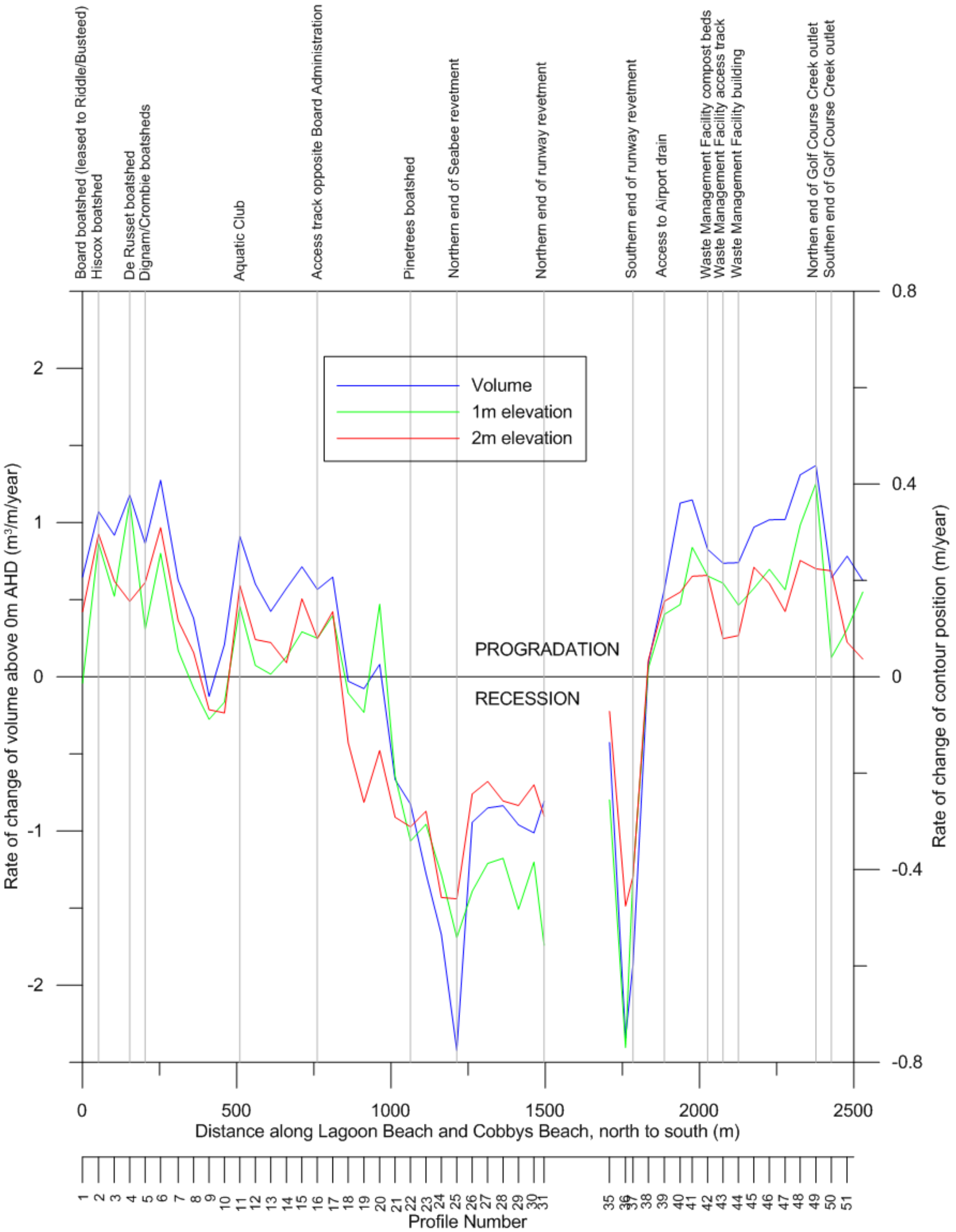

Figure B3: Rate of change of volume above 0m AHD, and rate of change of position of 1m and 2m AHD contours (both for the 1965 to 2011 period), along Lagoon Beach and Cobbys Beach (raw data, landward limit 10m landward of 2011 sand/vegetation interface)

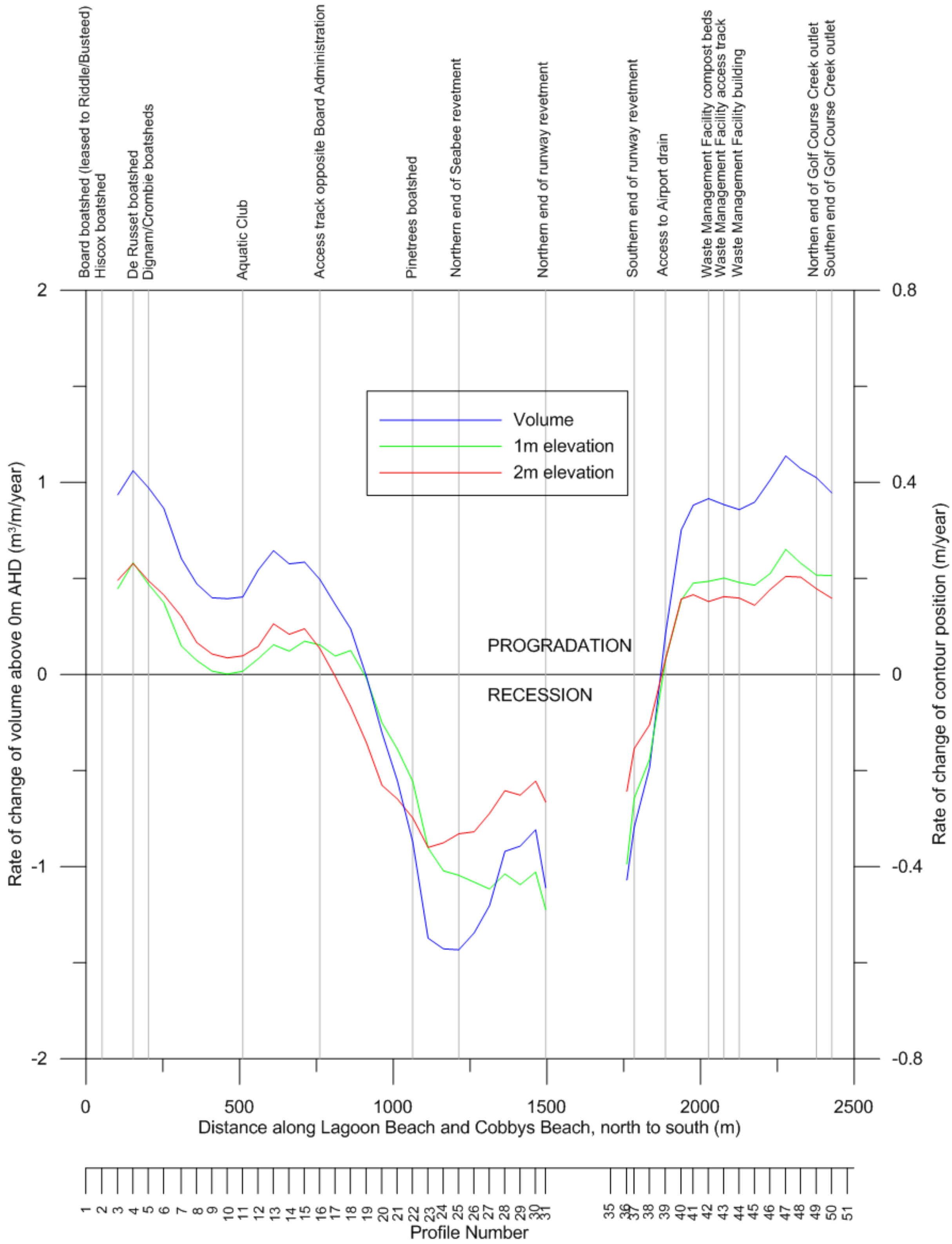

Figure B4: Rate of change of volume above 0m AHD, and rate of change of position of 1m and 2m AHD contours (both for the 1965 to 2011 period), along Lagoon Beach and Cobbys Beach (smoothed data, landward limit 10m landward of 2011 sand/vegetation interface)

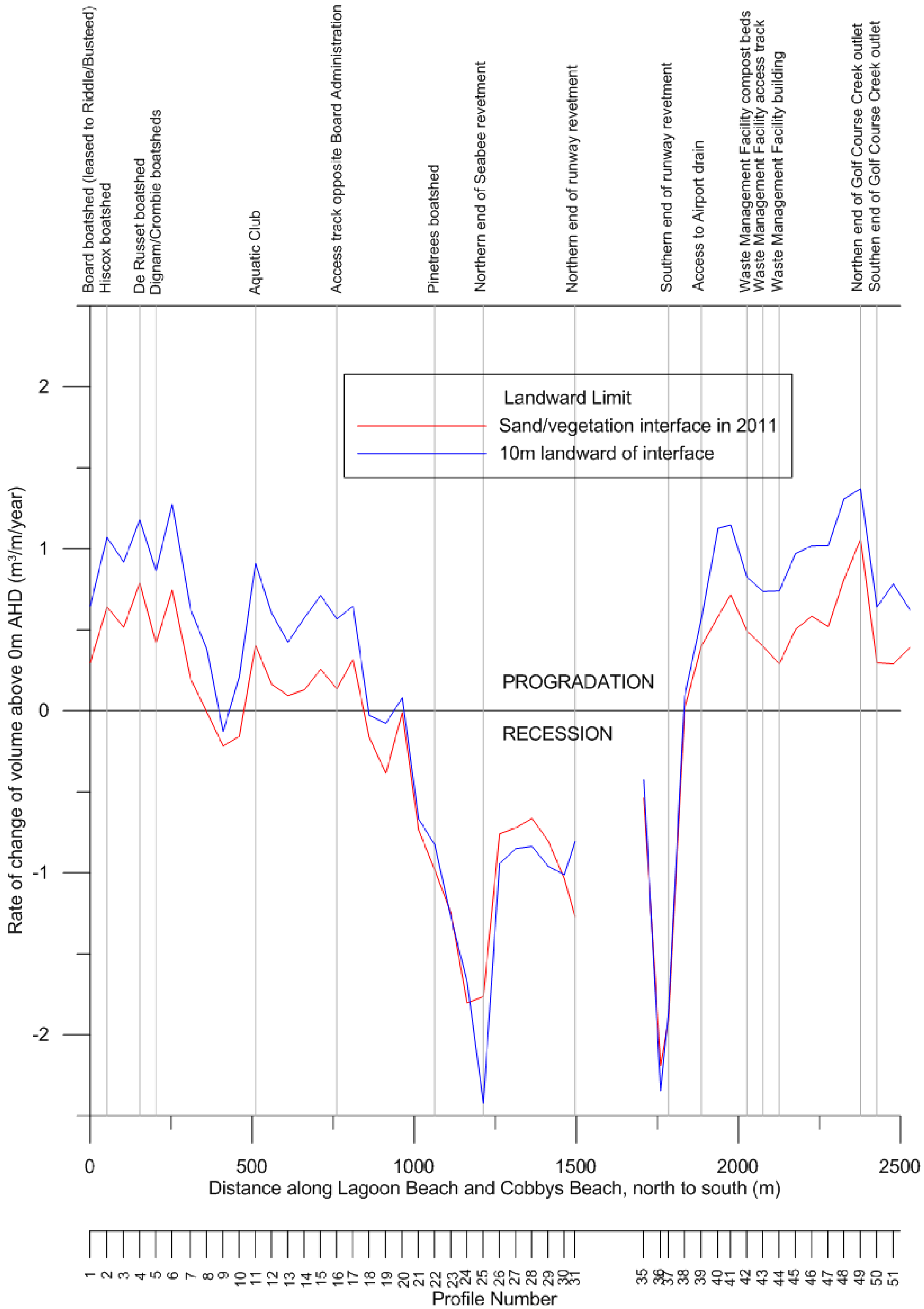

Figure B5: Comparison of volume change analysis for 1965 to 2011 using two different landward profile limits (raw data)

Summaries of the volumetric and positional changes are depicted in Figure B6 (north end of Lagoon Beach), Figure B7 (south end of Lagoon Beach and adjacent to the Seabee seawall) and Figure B8 (Cobbys Beach). These Figures also have the position of 0m and 2m AHD contour levels in 1965 and 2011 depicted, as a useful visualisation of the horizontal movement in these levels over time.

An overall summary of volumetric changes in various compartments along Lagoon Beach and Cobbys Beach is provided in Figure B9. Volumes are given for landward limits at both 10m and 20m landward of the 2011 sand/vegetation interface.

It is evident that from 1965 to 2011, based on linear regression using 5 dates, spatially averaged rates of change were as listed in Table B1. Note that the 10m and 20m limits shown refer to distances of 10m and 20m respectively landward of the sand/vegetation interface as the landward profile limit.

Table B1: Summary of 1965 to 2011 volume and elevation position rates of change along Lagoon Beach and Cobbys Beach (positive is progradation, negative is recession)

Location	Volumetric ($m^3/m/year$)		Volumetric ($m^3/year$)		Elevation (m/year)
	10m limit	20m limit	10m limit	20m limit	
Northern end of Lagoon Beach (north of 140m north of Pinetrees boatshed)	+0.7	+0.8	+560	+700	+0.1 (0, 1 & 2m AHD)
Southern end of Lagoon Beach (from south of 140m north of Pinetrees boatshed) and adjacent to Seabee seawall	-0.9	-0.8	-540	-520	-0.3 (0, 1 & 2m AHD)
Northern end of Cobbys Beach (80m length south of runway revetment)	-1.5	-1.5	-160	-160	-0.5 (1m elevation)[9]
Cobbys Beach (from 80m south of runway revetment)	+0.9	+1.1	+620	+770	+0.2 (0, 1 & 2m AHD)

For the 10m limit there was net progradation over the entire area analysed along Lagoon Beach and Cobbys Beach of 480m^3/year, and net progradation of 790m^3/year for the 20m limit. Therefore, there has been a net infeed of sediment into the compartments depicted in Figure B9. This is considered to be most likely due to onshore transport of sediment from the Lagoon and possibly some alongshore transport of sediment into Cobbys Beach from the south (and also possibly alongshore transport along Lagoon Beach to the north).

To investigate the contribution to the volume changes of the various time periods between photogrammetric dates, plots of volume change in each period were derived as shown in Figure B10. The rates were smoothed using a running average with a window width of 5.

[9] Rates were -0.6 and -0.3m/year at 0 and 2m elevation respectively.

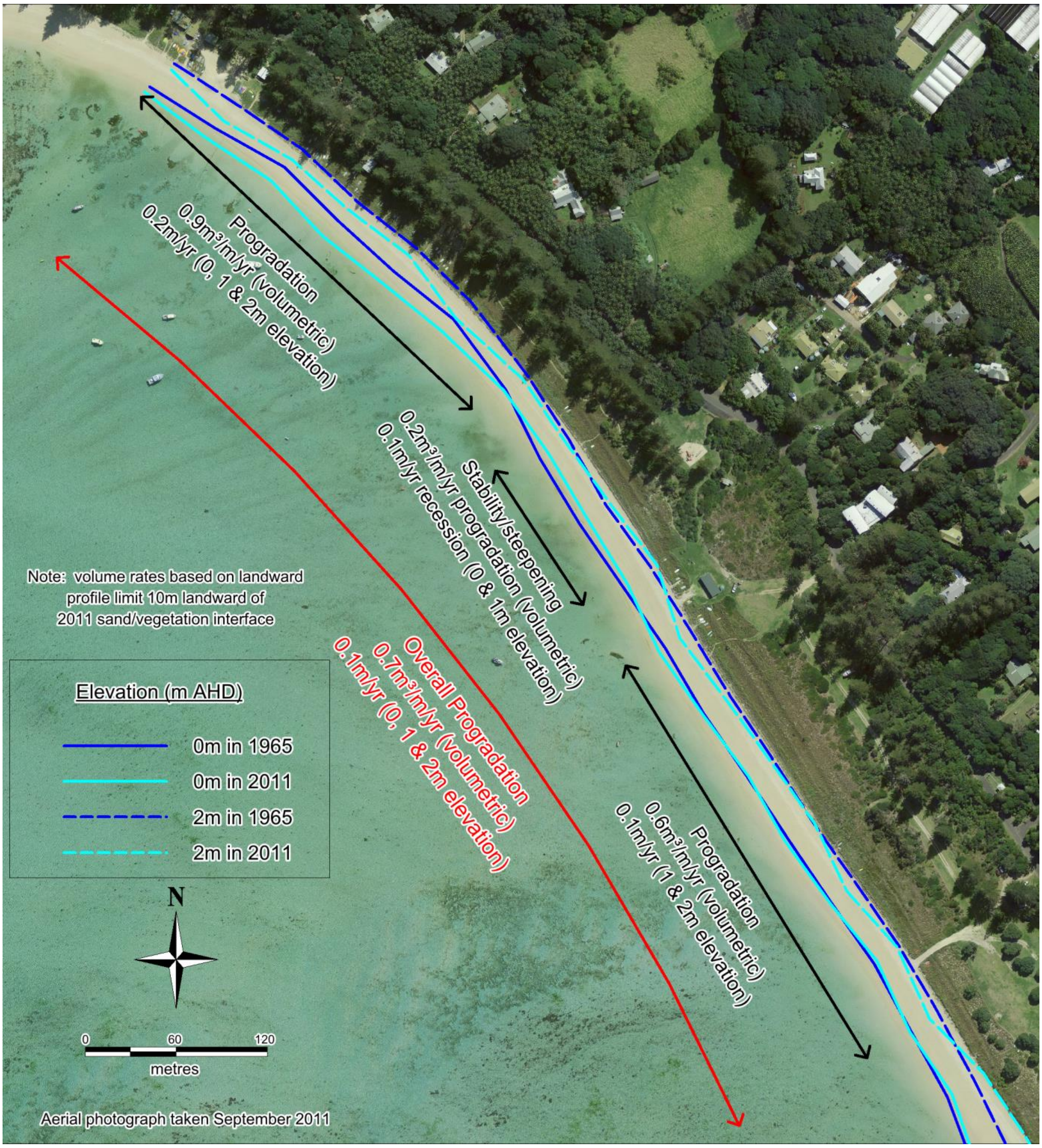

Figure B6: Summary of 1965 to 2011 volume and elevation rates of change along northern end of Lagoon Beach

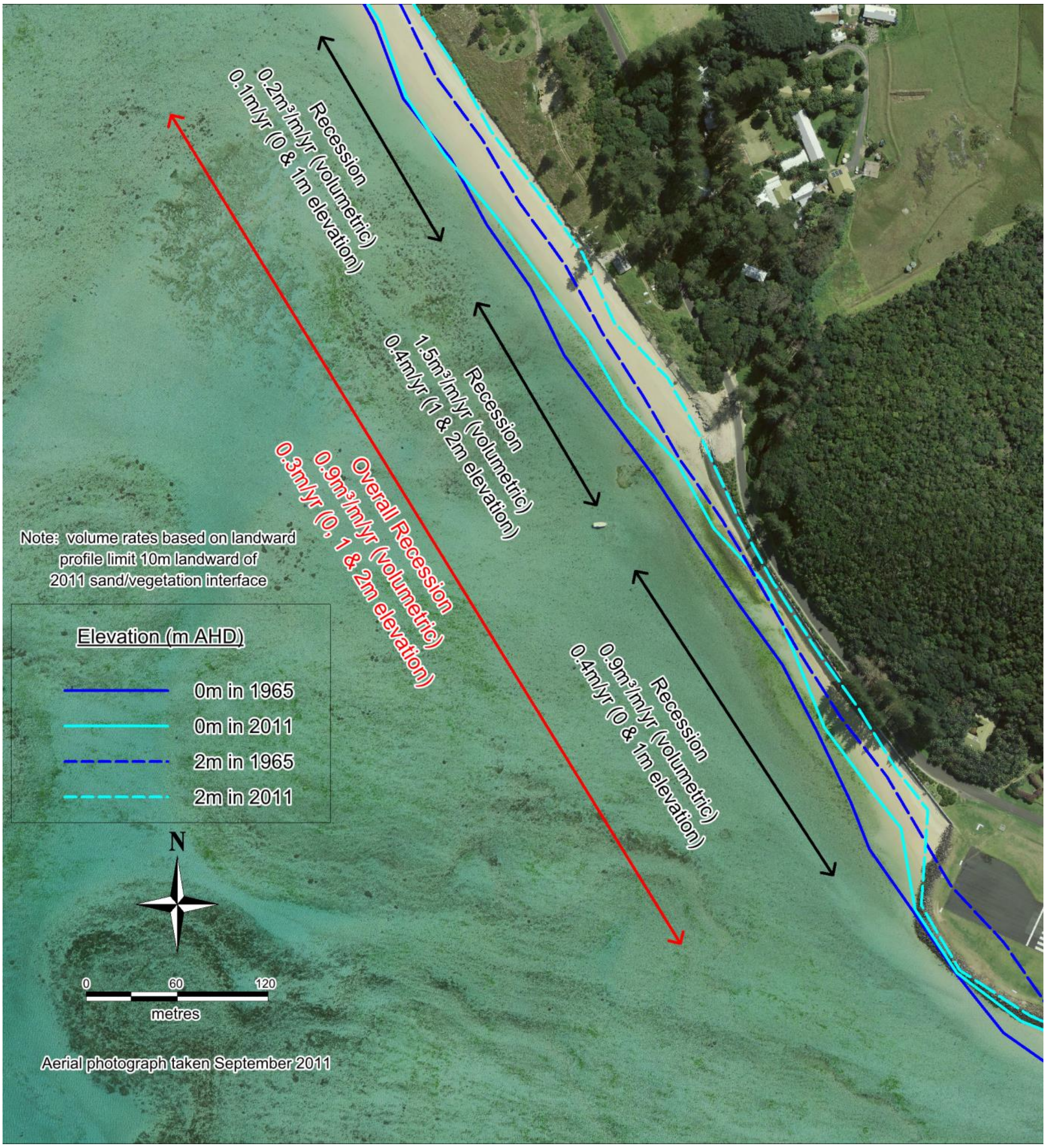

Figure B7: Summary of 1965 to 2011 volume and elevation rates of change along southern end of Lagoon Beach and adjacent to Seabee seawall

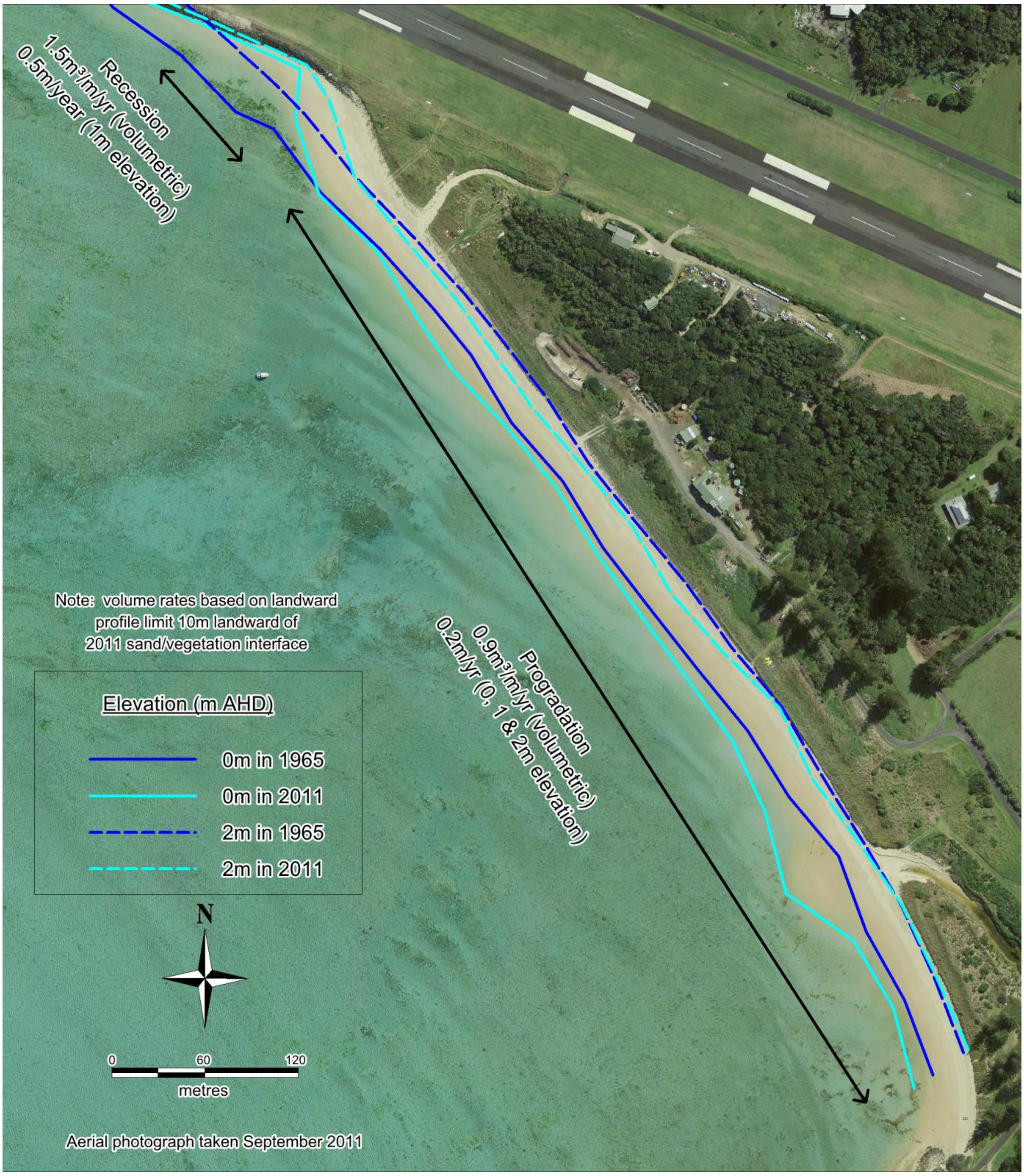

Figure B8: Summary of 1965 to 2011 volume and elevation rates of change along Cobbys Beach

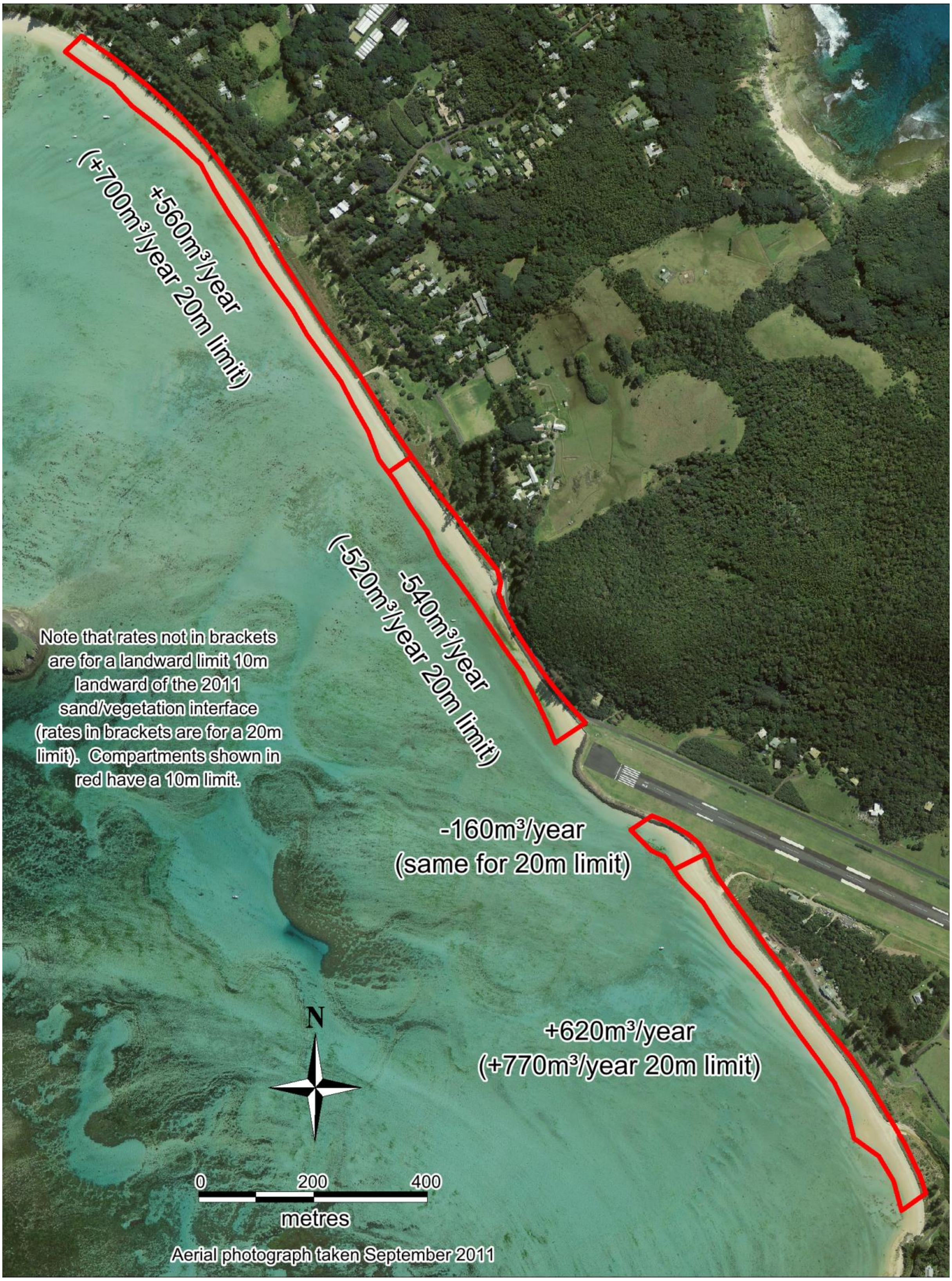

Figure B9: Summary rates of change of volume per year in various compartments along Lagoon Beach and Cobbys Beach (based on 1965 to 2011 rate in compartment)

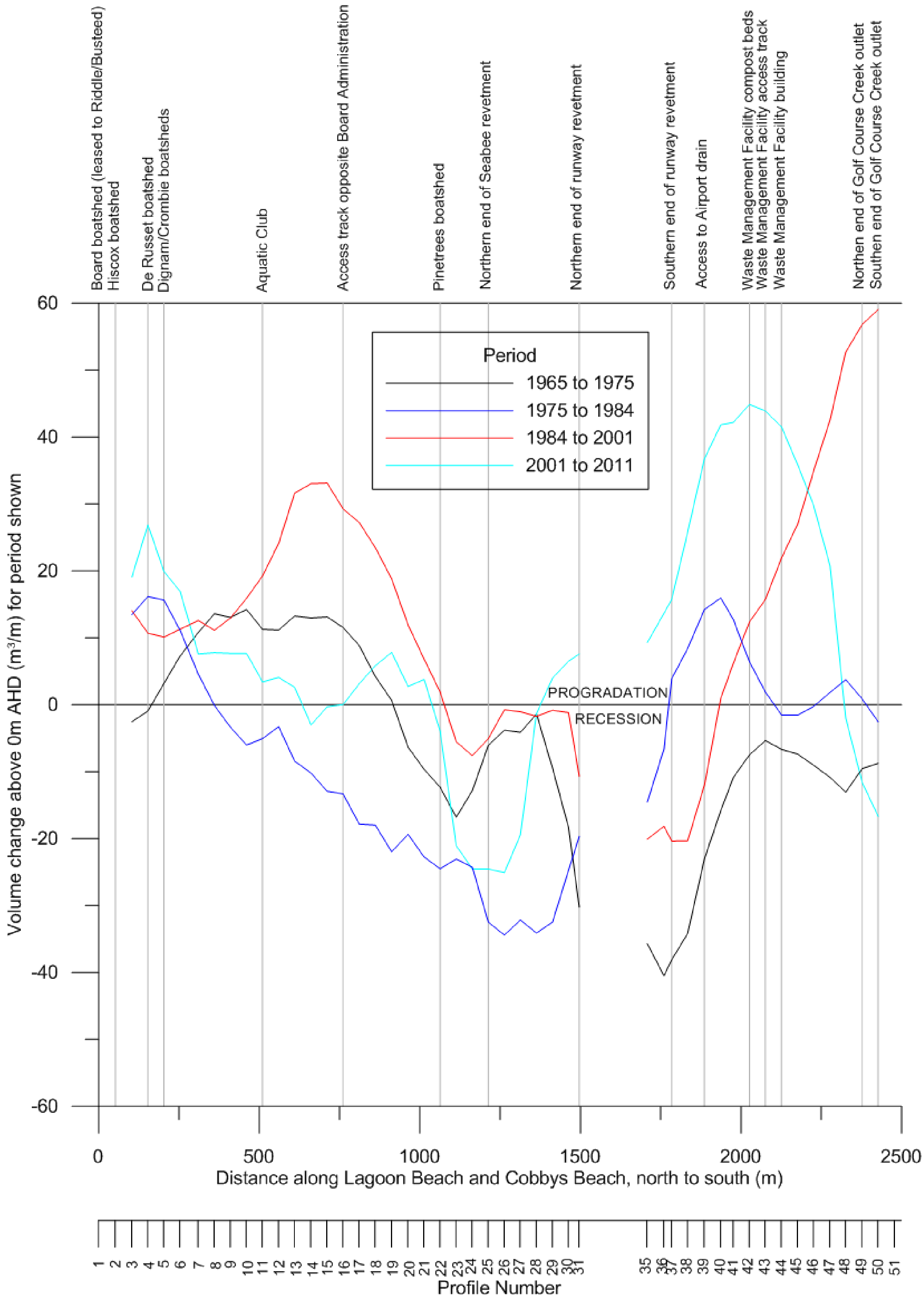

Figure B10: Volume change between each photogrammetric date along Lagoon Beach and Cobbys Beach (smoothed)

It is evident from Figure B10 that:

- from 1965 to 1975:
  - there were volume gains to the north of 100m north of Pinetrees boatshed (except not at the northern boatsheds) along Lagoon Beach;
  - there were volume losses along all of Cobbys Beach, particularly north of the Waste Management Facility;
- from 1975 to 1984:
  - there were volume gains at the northern boatsheds and then steadily increasing volume losses moving south to the runway revetment along Lagoon Beach;
  - moving south along Cobbys Beach there were volume losses for 80m south of the runway revetment, then volume gains as far south as the Waste Management Facility, and relative stability further south;
- from 1984 to 2001:
  - there were volume gains along Lagoon Beach to the north of Pinetrees boatshed, and relatively small losses south of that point to the northern end of the runway revetment;
  - there were volume losses over the northern 180m of Cobbys Beach and steadily increasing volume gains south of that point;
- from 2001 to 2011
  - there were volume gains along most of Lagoon Beach to the north of Pinetrees boatshed, and volume losses south of that point to 100m north of the runway revetment (with volume gains over the 100m north of the revetment); and
  - there were volume gains along most of Cobbys Beach, except south of Golf Course (Cobbys) Creek.

Overall, some general patterns emerge, namely:

- increasing volume gain or reducing volume loss moving north of Pinetrees boatshed along Lagoon Beach for most dates; and
- increasing volume gain or reducing volume loss moving south along Cobbys Beach to the Waste Management Facility for most dates.

To further investigate the contribution of the various periods between photogrammetric dates to the overall rates of change, plots of volume rates of change for each period (1965 to 1975, 1975 to 1984, 1984 to 2001, and 2001 to 2011) were derived, with the long term 1965 to 2011 volume rate determined by linear regression (as plotted in Figure B3) then subtracted (see Figure B11). The rates were smoothed using a running average with a window width of 5.

Positive plotted rates mean that a higher rate of progradation occurred for the period than the 1965 to 2011 (long term) rate, or progradation occurred where there had been long term recession. Zero plotted rates mean that there was the same rate of progradation or recession for the period as the long term rate. Negative plotted rates mean that a lower rate of progradation occurred for the period than the long term rate, or recession occurred where there has been long term progradation.

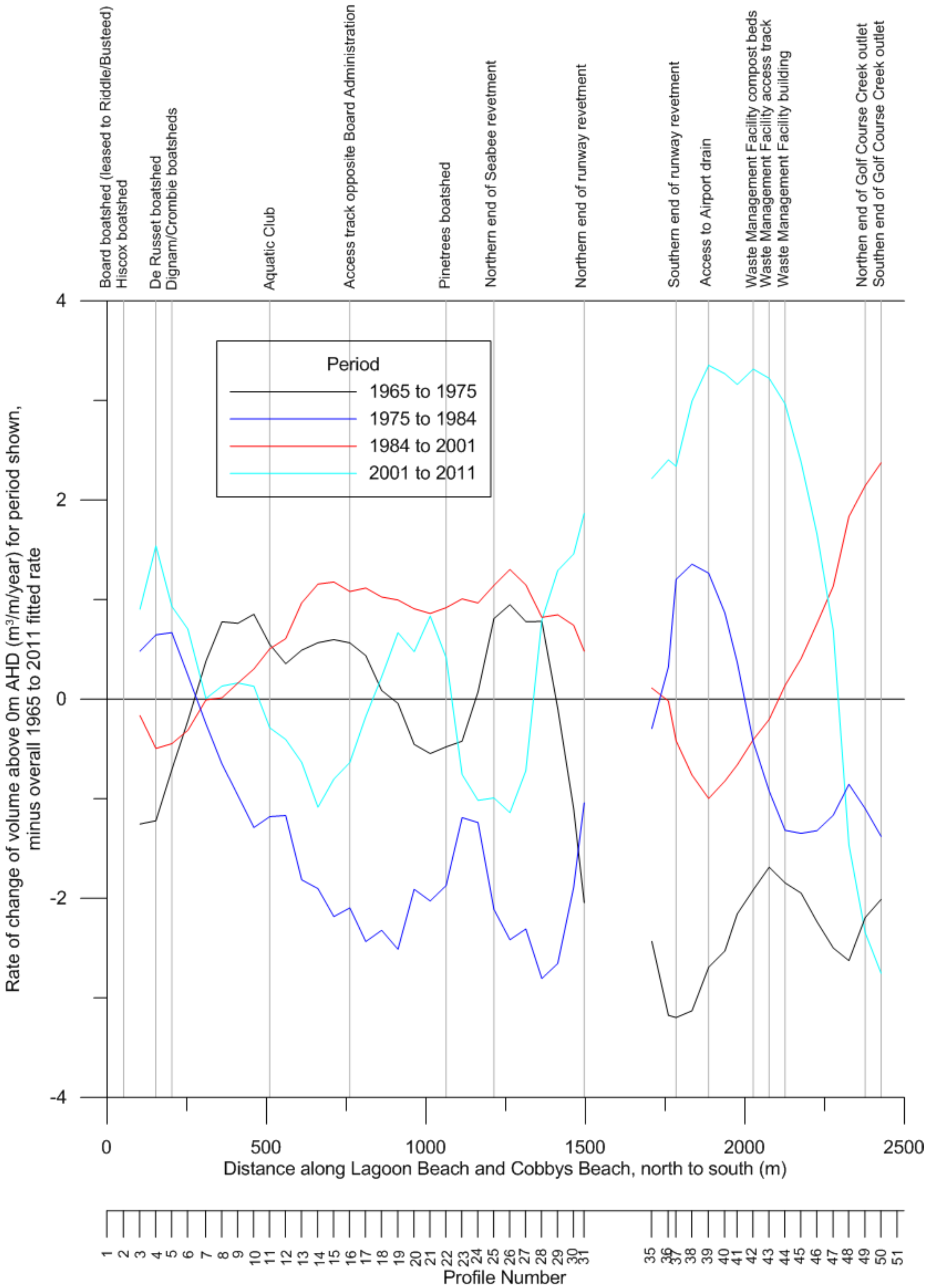

Figure B11: Rate of change of volume above 0m AHD for various periods, minus overall 1965 to 2011 fitted rate, smoothed

Key features in Figure B11 include the following:

- cyclic pockets of relative progradation and relative recession along Lagoon Beach from 1965 to 1975, and relative (and large) recession along Cobbys Beach for this period;
- relative (and large) recession from 1975 to 1984 along Lagoon Beach to the northern end of the runway revetment (except at the northern boatsheds), relative progradation for this period immediately south of the runway revetment at Cobbys Beach, and relative recession south of the Waste Management Facility at Cobbys Beach;
- relative progradation from 1984 to 2001 in most areas (except at the northern boatsheds and immediately south of the runway revetment; and
- cyclic pockets of relative progradation and relative recession along Lagoon Beach from 2001 to 2011 (almost mirroring the 1965 to 1975 pattern), and relative (and large) progradation along most of Cobbys Beach (except at the southern end).

B4. MOVEMENT OF SAND/VEGETATION INTERFACE

A technique that provides an indication of whether beaches have receded (shifted landwards or reduced in volume) or prograded (shifted seawards or increased in volume) is tracking the position of the sand/vegetation interface over time. Where visible, two interfaces were mapped, namely the incipient sand/vegetation interface (with light coverage of grasses and creepers landward of the interface) and the main frontal dune sand/vegetation interface (more densely vegetated landward). An example of these positions is depicted in Figure B12 (as visible on Lagoon Beach in 2011 near the Dignam/Crombie boatsheds).

Figure B12: Example definition of incipient and frontal dune sand/vegetation interfaces

The positions of the 1965 sand/vegetation interfaces at Lagoon Beach overlaid on a 2011 aerial photograph are provided in Figure B13 (northern half) and Figure B14 (southern half). The same information is depicted in Figure B15 for Cobbys Beach. Note that the terms "progradation" and "recession" used in these Figures are taken to be equivalent to seaward and landward migration of the interfaces respectively, for simplicity[10].

[10] It is possible that this is not always the case, for example that an interface moves landward on a prograding (growing in volume) profile, as vegetation growth can be affected by more factors than just sand volume (such as degree of trampling or rainfall).

Figure B13: Position of 1965 sand/vegetation interfaces at northern end of Lagoon Beach overlaid on 2011 aerial photograph

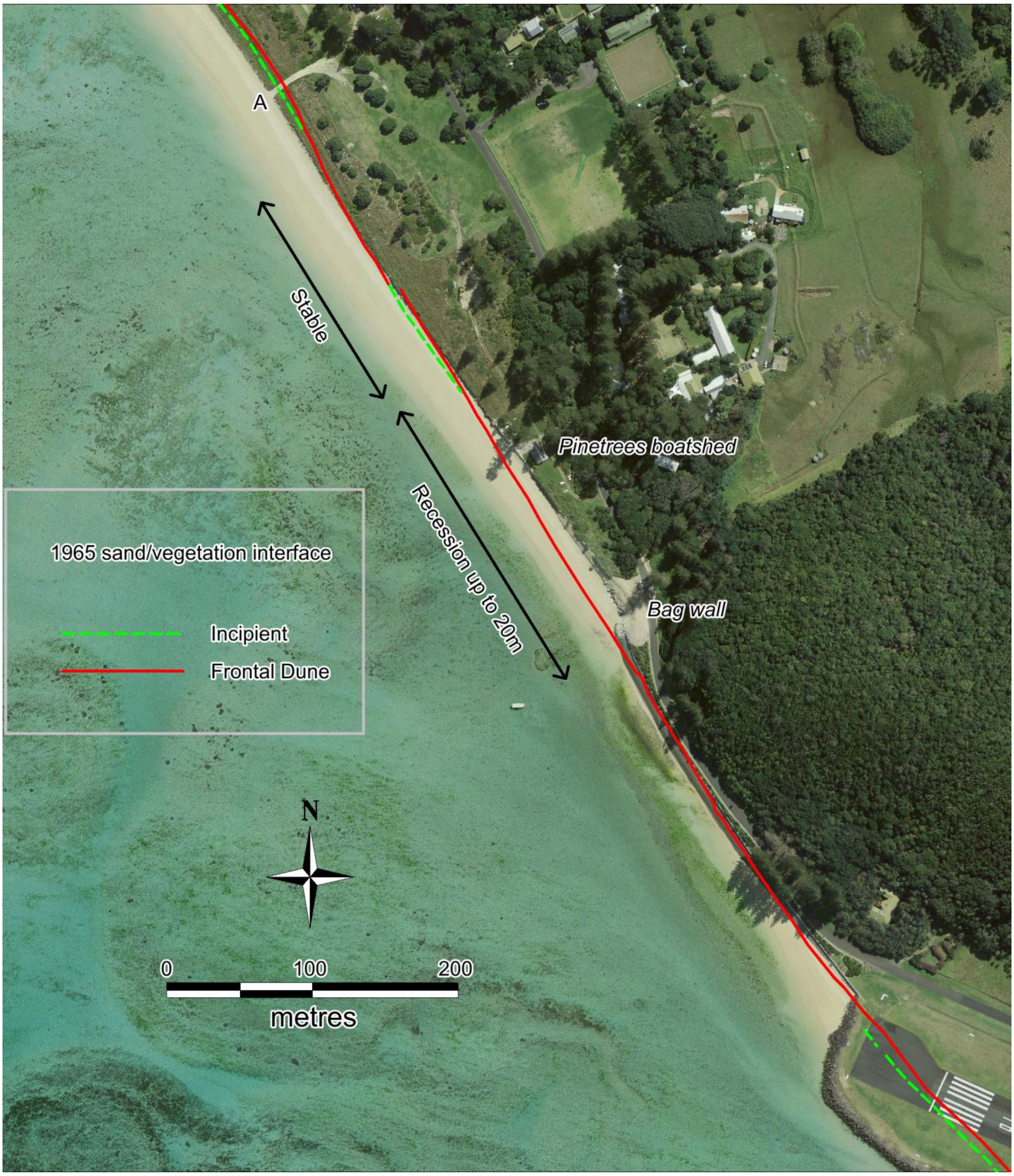

Figure B14: Position of 1965 sand/vegetation interfaces at southern end of Lagoon Beach overlaid on 2011 aerial photograph

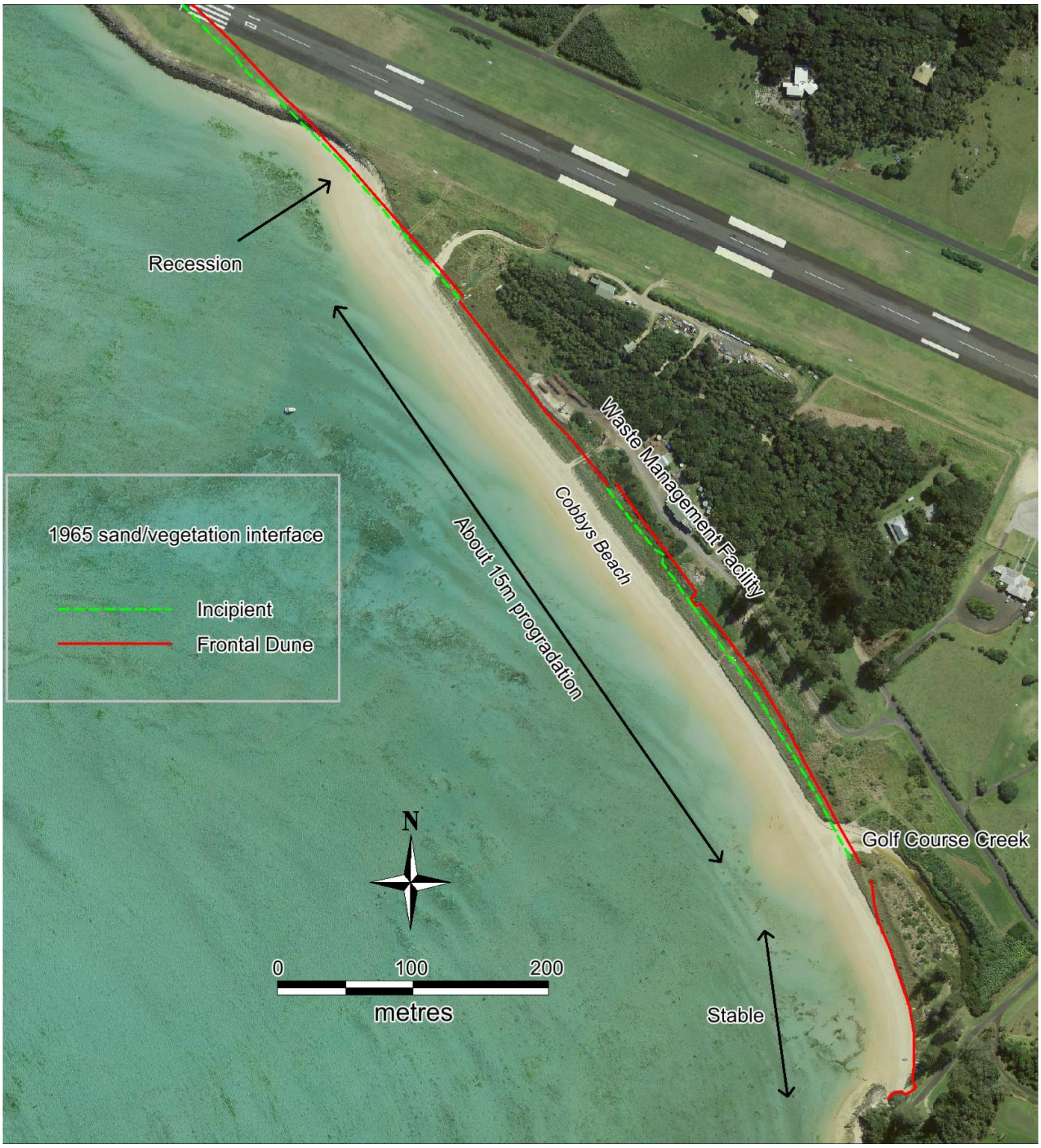

Figure B15: Position of 1965 sand/vegetation interfaces at Cobbys Beach overlaid on 2011 aerial photograph

It is evident that the sand/vegetation interface has migrated seaward (indicative of progradation) between 1965 and 2011 at most locations along Lagoon Beach and Cobbys Beach, namely:

- about 6m seaward at the northern-western end of Lagoon Beach (north-west of the boatsheds), see Figure B13;

- about 10m to 15 m seaward at the boatsheds at the northern end of Lagoon Beach continuing south past the Aquatic Club to the accessway (Location A in Figure B13) opposite the Board Administration offices (that is, over an alongshore distance of about 840m); and
- about 15m seaward adjacent to the Waste Management Facility and north to the Airport drain accessway and as far south as Golf Course (Cobbys) Creek at Cobbys Beach (that is over an alongshore distance of about 540m), see Figure B15.

Areas where the sand/vegetation interface has migrated landward (indicative of recession) between 1965 and 2011 comprise the following:

- over an alongshore distance of 220m north of the bag wall at Lagoon Beach, including (Figure B14):
    - landward migration of 13m at Pinetrees boatshed;
    - landward migration of 20m immediately north of the bag wall; and
- crenulate shaped landward migration of up to 15m immediately south of the runway revetment at Cobbys Beach, over an alongshore distance of about 80m (Figure B15);

The 1965 and 2011 sand/vegetation interfaces are approximately coincident along Lagoon Beach from about 80m to 210m south of Location A in Figure B14, and south of Golf Course (Cobbys) Creek at Cobbys Beach (Figure B15), indicative of relative stability.

For intermediate dates, it can be noted that:

- there was about 5m landward migration of the sand/vegetation interface between 1975 and 1984 along most of the present Seabee seawall location;
- most (about 75%) of the seaward interface migration north of the Aquatic Club at Lagoon Beach occurred between 1975 and 1984;
- between the Aquatic Club and the southern limit of the "about 10 to 15m progradation" region in Figure B13, about one-third to two-thirds of the seaward interface migration occurred between 1975 and 1984, and the other one-third to two-thirds between 1984 and 2001 (with the larger change for the 1975 to 1984 period in the north, and 1984 to 2001 period in the south);
- the "stable area" in Figure B14 had generally coincident interfaces over the 1965 to 2011 record, except that 1975 was about 5m further landward, particularly in the north;
- most (75%) of the landward migration in the "Recession up to 20m area" at the southern end of Lagoon Beach occurred between 2001 and 2011, for example:
    - at Pinetrees boatshed the interface moved 3m landward from 1965 to 1975, then 3m seaward from 1975 to 1984, then 3m landward from 1984 to 2001, then 10m landward from 2001 to 2011;
    - at the southern end the interface moved 4m landward from 1965 to 1975, then 2m seaward from 1975 to 1984, then 3m landward from 1984 to 2001, then 15m landward from 2001 to 2011;
- the "recession" interface at the northern end of Cobbys Beach moved about 3m seaward between 1965 and 1975, up to about 7m seaward between 1975 and 1984, up to 17m landward between 1984 and 2001, and around 8m landward between 2001 and 2011;
- the "about 15m progradation" interface depicted in Figure B15 at Cobbys Beach has generally progressively moved seawards, namely stable between 1965 and 1975, about 5m seaward at 1984, about 5m further seaward at 2001, and again about 5m further seaward at 2011; and
- the "stable" interface depicted in Figure B15 at Cobbys Beach did migrate about 5m to 10m landward between 1965 and 1975, half recovered by 1984, and fully recovered by 2001.

To summarise, the sand/vegetation interface along most of Lagoon Beach and Cobbys Beach moved about 10m to 15m seaward between 1965 and 2011, with about 75% occurring between 1975 and 1984 at Lagoon Beach and more progressive change at Cobbys Beach. The main exceptions are:

- the “stable” area in Figure B14 which had generally coincident interfaces over the 1965 to 2011 record;
- landward migration over the southern 220m of Lagoon Beach from north of the bag wall (up to 20m at the southern end, and 13m at Pinetrees boatshed), with about 75% occurring between 2001 and 2011; and
- an isolated fillet of landward migration immediately south of the runway on Cobbys Beach, over an alongshore distance of about 80m.

These patterns are generally similar to the volumetric and positional rates of change discussed in Section B3.

B5. EXAMPLE OF PROFILE CHANGES AT PINETREES BOATSHED

A plot of Profile 22 in Figure B1, the closest profile to Pinetrees boatshed (located 14m north of the boatshed), is provided in Figure B16. The five photogrammetric dates are depicted (in 1965, 1975, 1984, 2001 and 2011), as well as a profile derived from a LiDAR (aerial laser) survey completed by NSW Land and Property Information between 25 and 30 October 2012. Note that the zero chainage point is located at the landward extent of the profile depicted in Figure B1. The boatshed position is also shown, but note that its floor level is uncertain.

It is evident that beach volumes were reducing between 1975 and 1984, that would not have been visible as forming any erosion escarpment or loss of vegetation in the back beach area. That is, the losses in beach volume between 1975 and 1984 were manifested as a lowering of beach below about 3m AHD and steepening above that, which would only have been visible as a reducing subaerial beach width.

Between 1984 and 2001, the recession was mostly in the upper profile and would have begun to be visible as cutting into the vegetated dune. Between 2001 and 2011, the beach lowered at the seaward end and steepened in the back beach area as a typical erosion profile.

The photogrammetric data is most accurate in exposed beach areas where there is no vegetation. Where there is dense vegetation, the photogrammetric data can lack accuracy. The difference in levels between the 2012 LiDAR data and photogrammetric data evident at the crest of the dune may be related to this. That is, it is unlikely that elevations increased in the dunal area as depicted between 2011 and 2012.

That stated, the general trend of increasing dune crest elevations over time in the photogrammetric data is noteworthy. If this is realistic, this may be indicative of windblown sand being transported over the erosion escarpment and landward into the dunal area, then being trapped by vegetation and increasing the dune crest height. Historical beach scraping practices may have contributed to this process due to mounds of sand being placed at the base of the erosion escarpment, which could then be mobilised and transported into the dune under the dominant south-westerly winds.

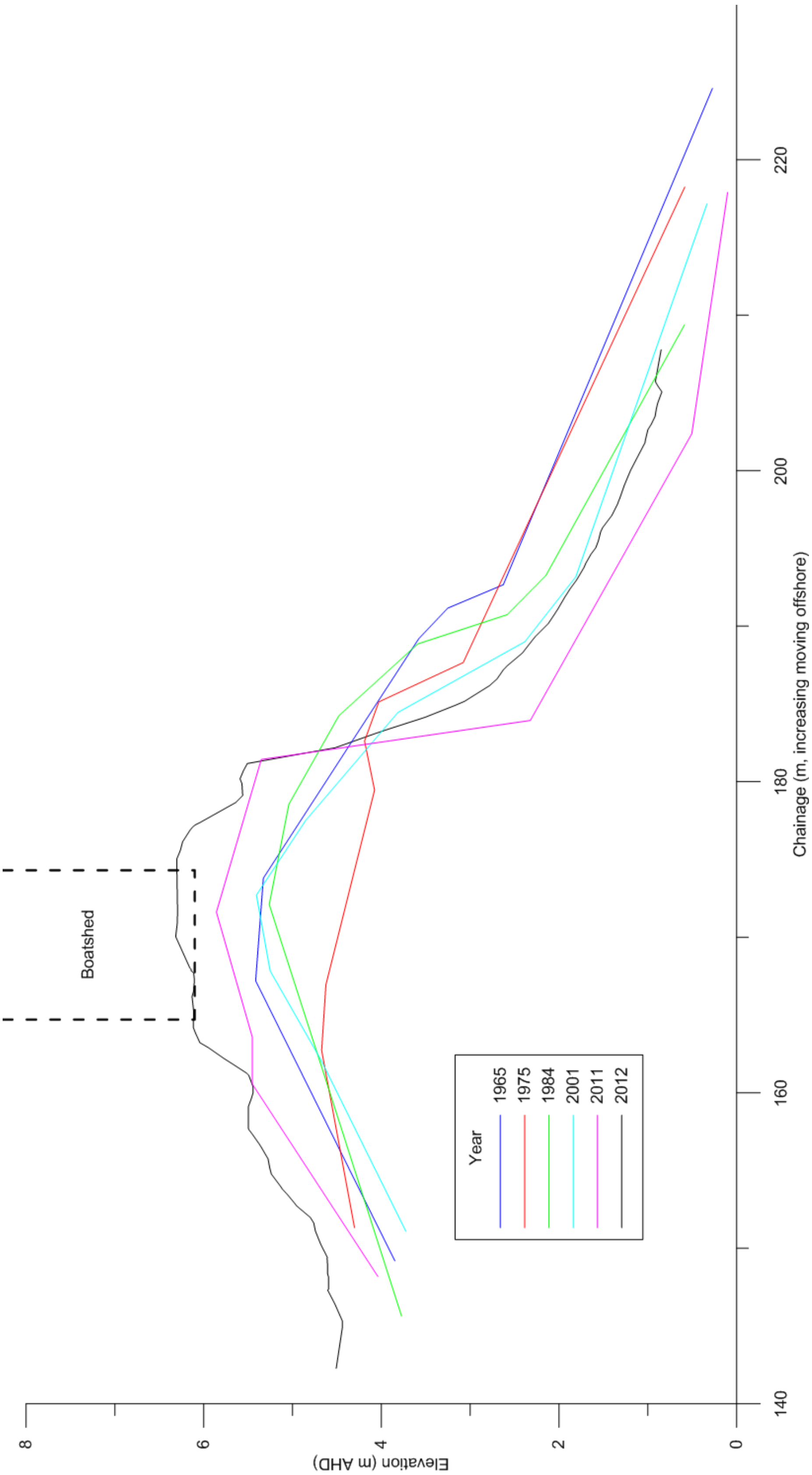

Figure B16: Variation in beach profile near Pinetrees boatshed over time

APPENDIX C
ANALYSIS OF SEDIMENT SAMPLES

CONTENTS

C1. BACKGROUND

In August 2012, 64 sediment samples were collected at Lord Howe Island by Haskoning Australia staff, namely at:

- Lagoon Beach (samples L1 to L26);
- Cobbys Beach (denoted as "South Runway Beach" herein, samples SR1 to SR4);
- in the Lagoon waterway (samples W1 to W16);
- Blinky Beach (samples B1 to B6);
- Neds Beach (samples N1 to N8); and
- Middle Beach (samples M1 to M4).

In May 2013, Haskoning Australia collected a further 29 samples from Lagoon Beach along three cross-shore transects, namely:

- at the Douglass Prodive boatshed at the northern end of Lagoon Beach (Transect A);
- 90m south of the Aquatic Club (Transect B); and
- at Pinetrees boatshed (Transect C).

The sediment sampling locations are depicted in Figure C1 (Lagoon Beach and northern Lagoon waterway), Figure C2 (South Runway Beach and southern Lagoon waterway), Figure C3 (Blinky Beach), Figure C4 (Neds Beach) and Figure C5 (Middle Beach). A brief description of the sample locations is provided in Table C1.

Selected photographs of the sampling are provided in Section C2.

Analysis of selected samples was undertaken by a sedimentologist, Dr Ed Frankel of Vibrosed Analytical (and formerly of the University of Technology Sydney), as discussed in Section C3.

The May 2013 samples were not analysed by Dr Frankel, only being analysed visually. It was evident from visual inspection that the sediment particle size was substantially coarser near the mean water level location on the beach.

Figure C1: Lagoon Beach and northern Lagoon waterway sediment sampling locations

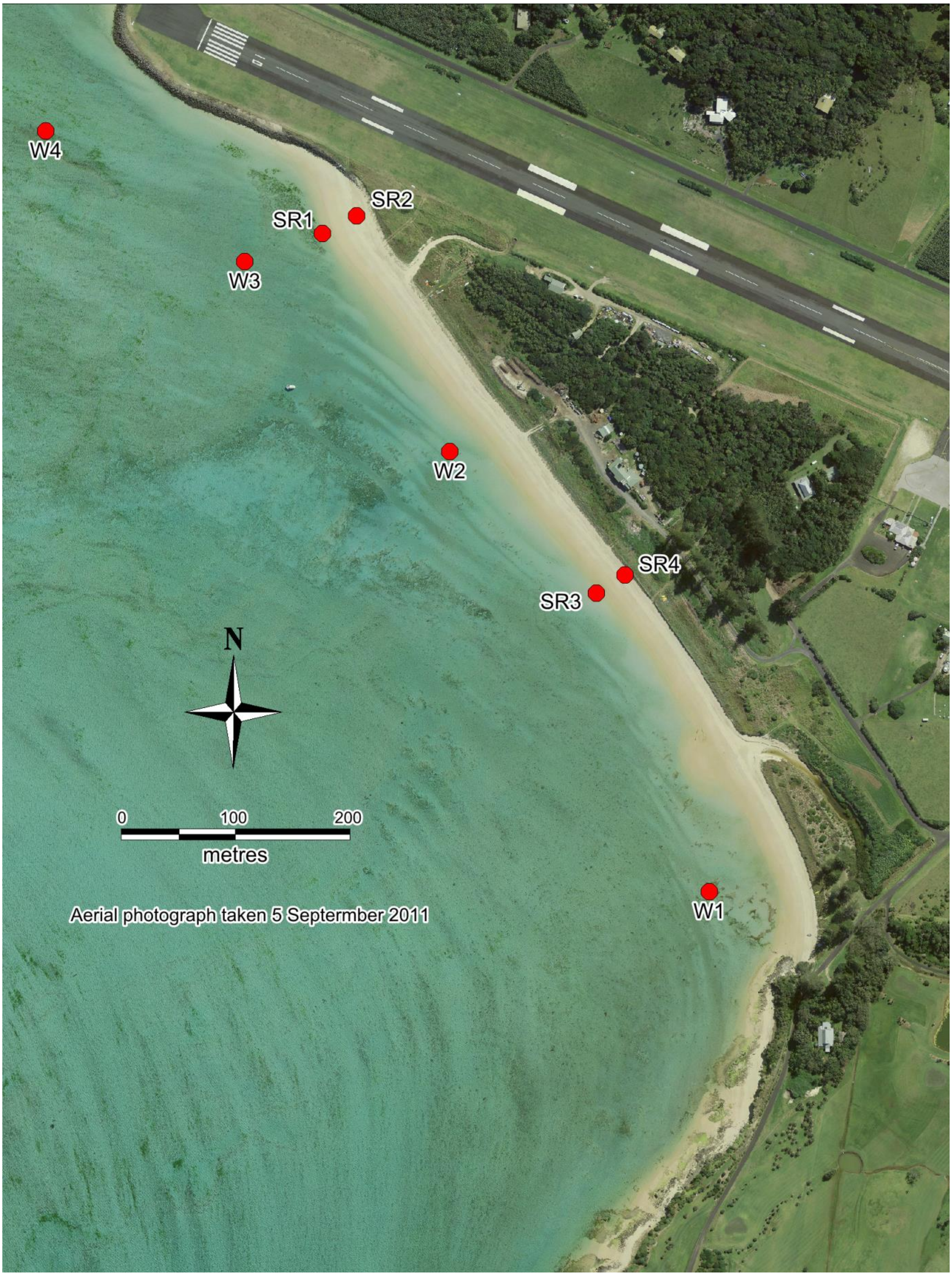

Figure C2: South Runway (Cobbys) Beach and southern Lagoon waterway sediment sampling locations

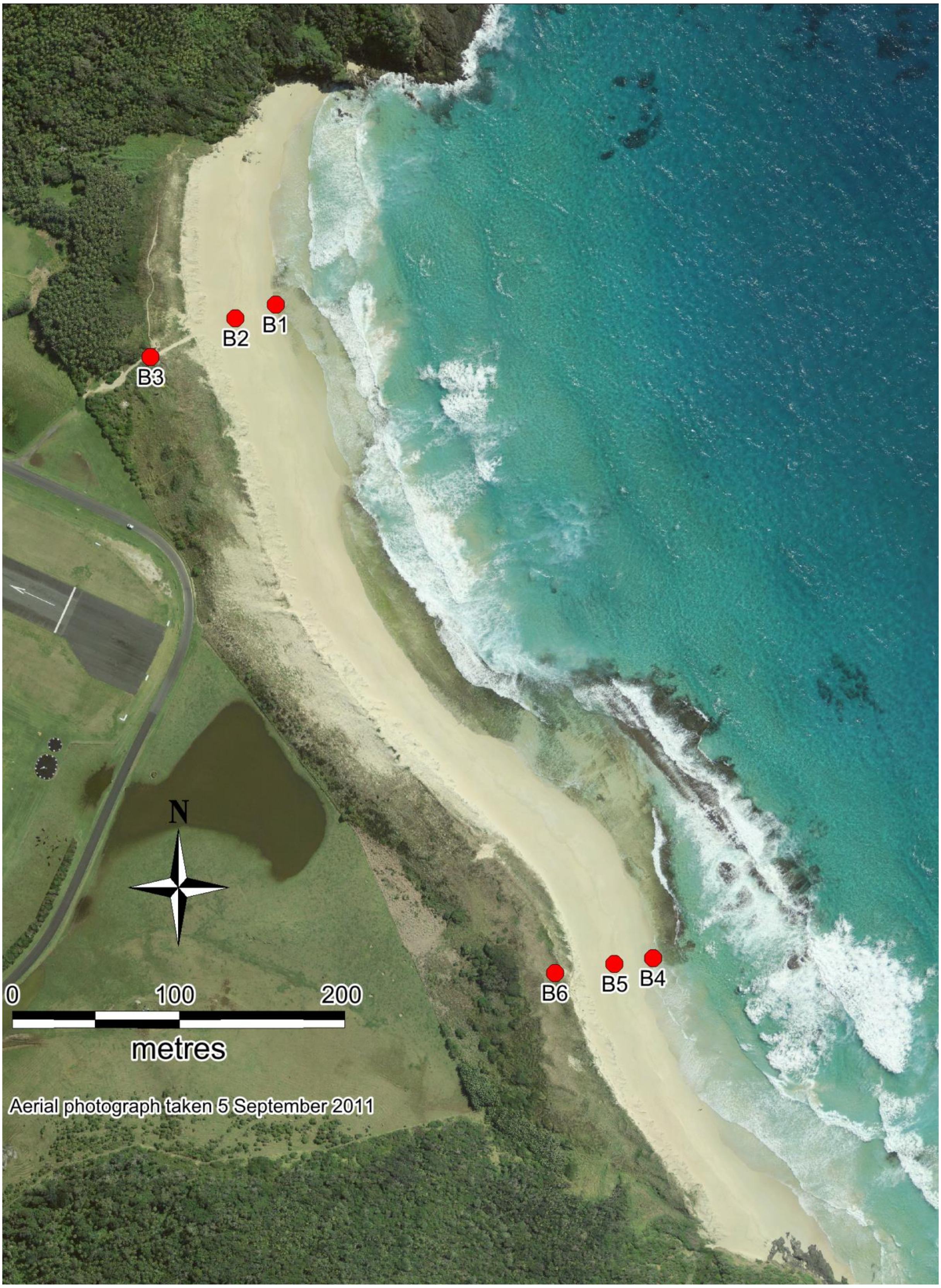

Figure C3: Blinky Beach sediment sampling locations

Figure C4: Neds Beach sediment sampling locations

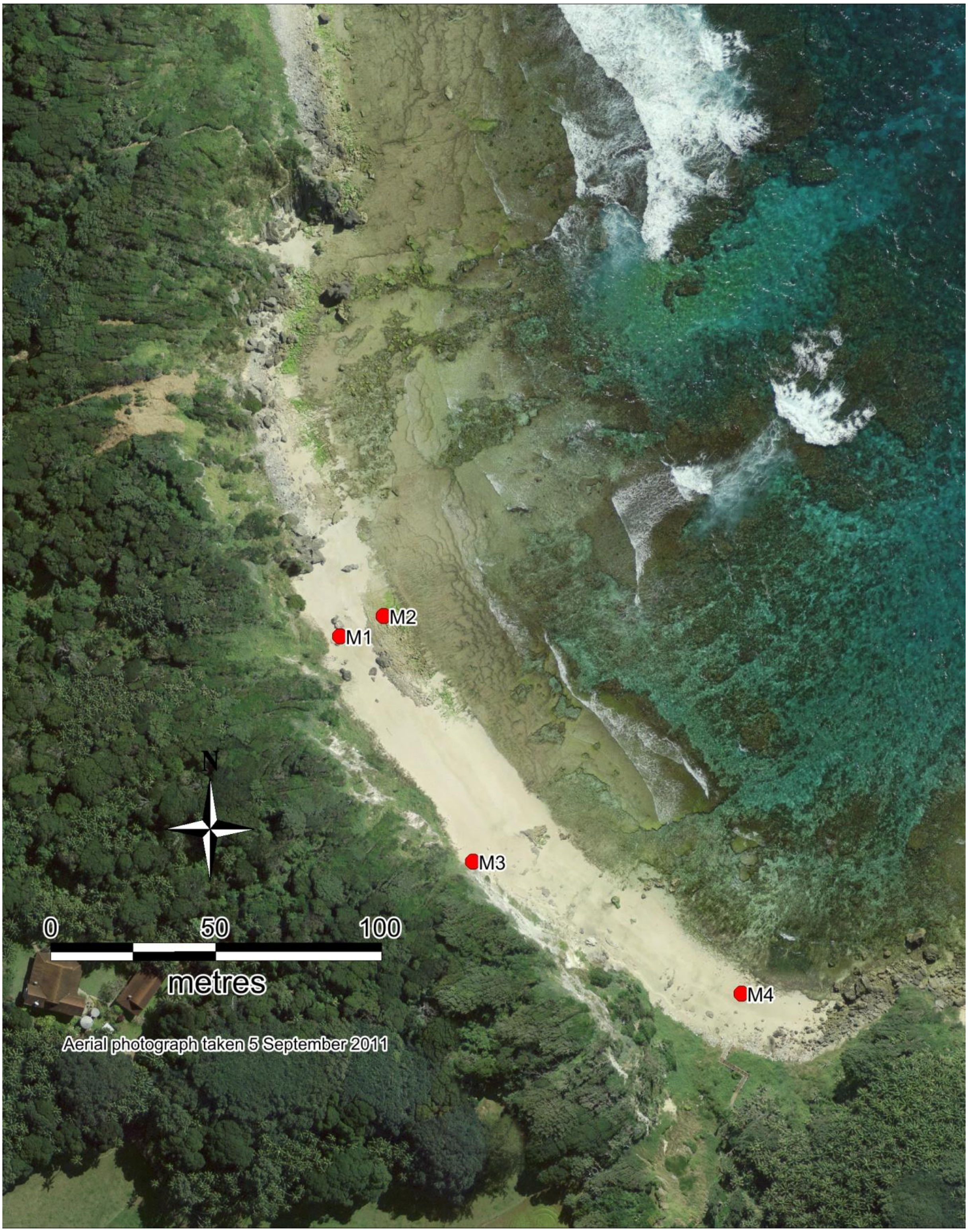

Figure C5: Middle Beach sediment sampling locations

Table C1: Description of sediment sampling locations

Sample	Notes
L1	3m landward of water level
L2	L1 section, 3m seaward of visible base of Seabees
L3	1m landward of water level and 13m seaward of visible base of Seabees
L4	L3 section, 1.5m seaward of visible base of Seabees
L5	1m landward of water level
L6	L5 section, from eroding bank 4-5m high
L7	L7,8,9 same section. 1m landward of water level
L8	High Water Mark
L9	0.5m up 1.8m high scarp
L10	1m landward of water level. Beach 35m wide cross-shore from water level to scarp
L11	L10 section. At High Water Mark
L12	1m landward of water level
L13	L12 section. At High Water Mark
L14	3m landward of water level
L15	L14 section. At most seaward line of shells. 21m from L14 to L15
L16	1m landward of water level.
L17	L16 section . At Spinifex edge. 20m from water level to L17
L18	1m landward of water level
L19	L18 section, at High Water Mark. 5m seaward of scarp
L20	1m landward of water level
L21	L20 section, 5m seaward of scarp edge. 16m from water level to scarp edge and vegetation line
L22	1m landward of water level
L23	L22 section. 25m landward of water level.
L24	In dune (sand builds up in this area and is removed monthly for slipway access)
L25	1m landward of water level
L26	L25 section at High Water Mark, 25m from water level
W1 to W16	Note that all W samples were obtained off a boat
SR1	1m landward of water level (sample lost)
SR2	Same section as SR1, at High Water Mark (34m from water level)
SR3	1m landward of water level
SR4	Same section as SR3, at High Water Mark (32m from water level)
B1	B1 to B3 in section. At water level.
B2	26m landward of water level
B3	At dune crest, about 94m landward of water level
B4	B4 to B6 in section. 10m landward of water level.
B5	29m landward of water level, near High Water Mark

Sample	Notes
B6	62m landward of water level, in dune
N1	Edge of boulders
N2	Near water level
N3	20m cross-shore along beach to Spinifex edge
N4	Heavily weathered calcarenite at back of beach (tube shapes to 10cm long)
N5	3m landward of water level on beach
N6	Edge spinifex
N7	3m landward of water level on beach
N8	7m landward of High Water Mark, 8m seaward of vegetation line
M1	Rock, recent scree at base of vegetation
M2	Sand, edge of bedrock in lower beach
M3	Brown, striated cemented sand with shell, below "white" bluff at back of beach
M4	3m landward of water level on beach

C2. SAMPLING PHOTOGRAPHS

Figure C6: L7, L8 and L9 sampling area near Pinetrees boatshed

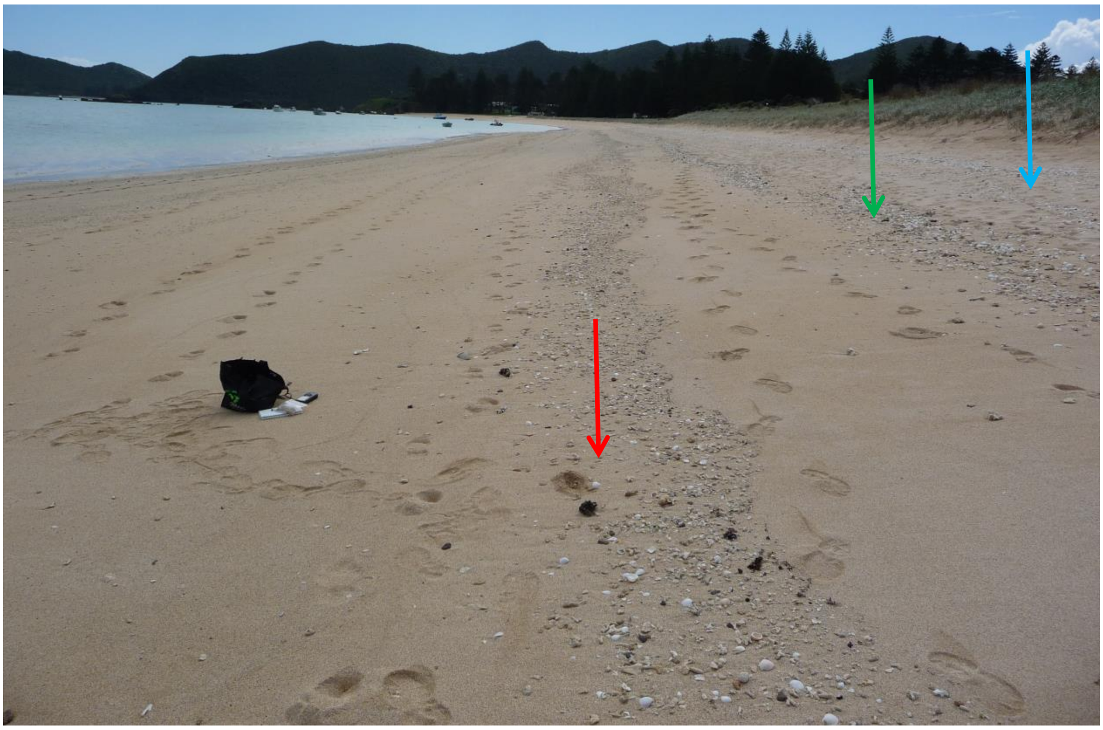

Figure C7: L15 sampling location at red arrow (note two more landward lines of shells at green and blue arrows respectively)

Figure C8: Elevated view of L15 sampling area with three lines of shells

Figure C9: B4, B5 and B6 sampling area at Blinky Beach

Figure C10: N4 sampling area

Figure C11: Collecting N4 sample

Figure C12: Collecting N8 sample

Figure C13: M1 sampling area (scree at base of slope)

Figure C14: M3 sampling area

C3. ANALYSIS RESULTS

C3.1 General Nature of Reef Sediments

This section is mostly sourced verbatim from information provided by Dr Ed Frankel.

Sediments in coral reefs are composed of the skeletal remains of a vast number of different organisms. In general, terrigenous[1] materials are absent, however they may be present in particular instances such as fringing reefs adjacent to land where considerable debris may be washed onto and into the reefs. In addition, offshore systems may be contaminated by inter-reef terrigenous materials washing into the reef under the influence of wave action in storms for example.

The huge variety of organisms that create, live in and on, and sometimes destroy coral reefs all grow to different sizes and have different skeletal architecture composed of complex components of different shapes and sizes. Skeletal parts also have different chemical compositions. In addition, the micro texture of the structures varies enormously. For example, the shell of a clam is large, relatively thick and dense and is consequently very robust and difficult to break down mechanically. By way of contrast, echinoderm ossicles are relatively small and have a delicate three dimensional open pore structure which breaks down readily even under mild mechanical conditions.

In addition different biota inhabit different ecological niches and consequently may not contribute to the composition of the sediment in those areas where they do not live.

For these reasons different depositional environments within reefs contain sediments of different sizes, compositions and textures. Consequently, 'classical' grain size studies are not usually of significant use in interpreting hydrodynamic conditions around these systems.

However in the case of Lord Howe Island, because of the nature of the problem at hand, even though the sediments are almost exclusively reef derived, it is possible to make some use of 'classical' grain size techniques. This is helped to a large extent by the somewhat restricted compositional makeup of the reef-lagoon, beach and dune sediments, as discussed in Section C3.2.

C3.2 Composition of Lord Howe Island Sediment Samples

The text below is mostly sourced verbatim from information provided by Dr Ed Frankel.

The marine sediments of the reefs, lagoon, dunes and beaches of Lord Howe Island were found to be composed of skeletal carbonates with less than 1% (and frequently only a trace) of terrigenous component. The latter, when present, was basaltic rock fragments and accessory ('heavy') minerals.

In general the sediments were predominantly sand sized (grain size between 62 microns and 2 mm) with gravel when present (greater than 2mm grain size and generally less than 25mm, that is mostly fine to medium gravel).

No mud (smaller grain size than 62 microns) was present in any of the materials examined. The lack of a mud sized fraction is quite common in coral reef lagoons even though these are ideal sediment sinks. It is probable that carbonate mud particles (micrite) are flushed from the systems almost as soon as they are formed by mechanical or bioerosion of the reef materials.

[1] Terrigenous sediment is derived from land erosion.

In the case of Lord Howe Island, mud produced in and on Neds, Middle and Blinky Beaches would be flushed by the ambient (relatively vigorous) wave climate. Lagoon Beach and Cobbys Beach and the Lagoon are probably more influenced by reasonably strong tidal currents and a somewhat gentler wave climate as the mud removal/dispersal mechanisms.

Gravel and sand occurred in varying proportions depending on where/when the samples were collected. Gravel was generally angular. The sands varied from finer to coarser overall and ranged through the entire spectrum of textural maturity from angular and 'dull' (immature) to well-rounded and polished (highly mature).

The coarser sediments were dominated by corals and molluscs with significant amounts of 'free' and encrusting coralline algae. In occasional instances large benthic foraminifera (for example *Marginopera* species) were present in the coarse sand and occasionally in the gravel. Only in the finer sand fractions were other components such as echinoderms, sponges and bryozoans present in anything other than trace amounts.

The proportion (by mass) of sand and gravel in each of the samples tested is provided in Table C2. As noted previously, the proportion of mud in all samples was 0%.

Table C2: Sand and gravel proportions in tested samples

Location	Sand proportion by mass (%)	Gravel proportion by mass (%)
L1	86.3	13.7
L2	100.0	0.0
L4	98.9	1.1
L5	62.6	37.4
L6	100.0	0.0
L7	47.8	52.2
L8	98.8	1.2
L12	74.7	25.3
L14	71.9	28.1
L18	100.0	0.0
L19	100.0	0.0
L20	100.0	0.0
L22	99.4	0.6
L23	100.0	0.0
W1	97.2	2.8
W2	96.4	3.6
W3	74.1	25.9
W4	72.8	27.2
W5	87.9	12.1
W7	89.7	10.3

Location	Sand proportion by mass (%)	Gravel proportion by mass (%)
W8	97.9	2.1
W9	96.9	3.1
W13	96.6	3.4
W14	96.6	3.4
W15	91.0	9.0
W16	89.3	10.7
SR1	100.0	0.0
SR2	100.0	0.0
SR3	97.9	2.1
SR4	100.0	0.0
B2	100.0	0.0
B3	100.0	0.0
B5	100.0	0.0
B6	100.0	0.0
N1	0.0	100.0
N2	100.0	0.0
N3	100.0	0.0
N5	100.0	0.0
N6	100.0	0.0
M3	100.0	0.0
M4	99.8	0.2

The text below is based on interpretation by Haskoning Australia.

Most Lagoon Beach tested samples were close to entirely sand sized. The samples with significant gravel proportions were L1, L5, L7, L12 and L14, which were all collected within a distance of 1m to 3m of the water level, in the southern half of the beach. Other samples collected near the water level in the northern half of the beach (L18, L20, L22) were close to entirely sand sized.

Most Lagoon Waterway tested samples were close to entirely sand sized. The samples with significant gravel proportions were W3 and W4 (and W5, W7, W15 and W16 to a lesser extent), which were all collected offshore of the southern half of Lagoon Beach and offshore of the northern end of Cobbys (South Runway) Beach. Samples W1, W2, W8, W9, W13 and W14 were close to entirely sand sized, and scattered offshore of the southern half of Cobbys Beach, northern half of Lagoon Beach (except W13 was in the south) and near North Passage.

All Cobbys (South Runway), Blinky, Neds and Middle Beach tested samples were close to entirely sand sized (except for N1).

The text below is mostly sourced verbatim from information provided by Dr Ed Frankel.

Compositional descriptions of the tested samples are provided in Table C3. Note that in the Lagoon Waterway (W samples) sands there were generally very minor amounts of foraminifera, echinoderms, sponges and crustaceans. Also note that:

- "a" means angular;
- "DP" means 'dull'/eroded/weathered/pitted;
- "M/C" refers to mollusc / coral and coralline algae (including encrusting);
- "P" means polished;
- "Pm" means slightly polished;
- "r" means rounded
- "sa" means subangular;
- "sr" means subrounded;

Table C3: Compositional description of tested samples

Location	Sand	Gravel	Sorting
L1	sr-r Pm M/C	M/C to10mm	well
L2	sr-r Pm M/C	-	well
L4	sa-r Pm M/C	M/C to 5mm	
L5	sa-sr Pm M/C	M/C to 20mm, rock fragments to 10mm	moderate
L6	a-sr M/C	-	moderate- well
L7	sa-r M/C	M/C to 20mm	
L8	sa-sr Pm M/C	M/C to 5mm	well
L12	sa-sr M/C	M/C to 10mm	moderate- well
L14	sa-sr M/C	M/C to 10mm	
L15[2]	sa-sr M/C	-	
L18	sa-sr Pm M/C	-	moderate- well
L19	sa-sr Pm M/C	-	well
L20	sa-sr M/C	-	
L22	sa-sr Pm M/C	M/C to 5mm	moderate- well
L23	sa-sr Pm M/C	-	moderate- well
W1	a-sr DP M/C	M/C to 10mm	
W2	a-sr DP M/C	M/C to 5mm	
W3	a-sr DP M/C	M/C to 5mm	
W4	a-sr DP M/C	M/C to 5mm	moderate- well
W5	a-sr DP M/C	M/C to 15mm	
W7	a-sr DP M/C	M/C to 10mm	moderate
W8	a-sr DP M/C	M/C to 5mm	moderate
W9	a-sr DP M/C	M/C to 10mm	moderate
W13	a-sr DP M/C	M/C to 5mm	

[2] Note that L15 did not have particle size testing undertaken.

Location	Sand	Gravel	Sorting
W14	a DP M/C	M/C to 5mm	
W15	a DP M/C	M/C to 15mm	poor
W16	a M/C	M/C to10mm	
SR2	a M/C	-	moderate- well
SR3	a M/C	M/C to 5mm	
SR4	a M/C	-	moderate
B2	r-wr P M/C <1% rock fragments	-	very well
B3	wr P M/C <1% rock fragments	-	very well
B5	wr P M/C <1% rock fragments	-	Well
B6	wr P M/C <1% rock fragments	-	Well
N1	-	rock fragments 25-50mm	
N2	a-r Pm M/C 3% rock fragments	-	very well
N3	a-r P M/C 3% rock fragments	-	
N5	a-sr P M/C 3% rock fragments	-	well
N6	a-sr Pm M/C 3% rock fragments	-	
M3	sa-sr DP M/C	-	moderate
M4	sr-wr P M/C	C to 5mm	