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)

HASKONING AUSTRALIA

a company of Royal HaskoningDHV

Suite 5, Level 5
100 Walker Street
NORTH SYDNEY NSW 2060
T: +61 (0) 2 8854 5000
F: +61 (0) 2 9929 0960
www.royalhaskoningdhv.com
ABN 66 153 656 252

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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

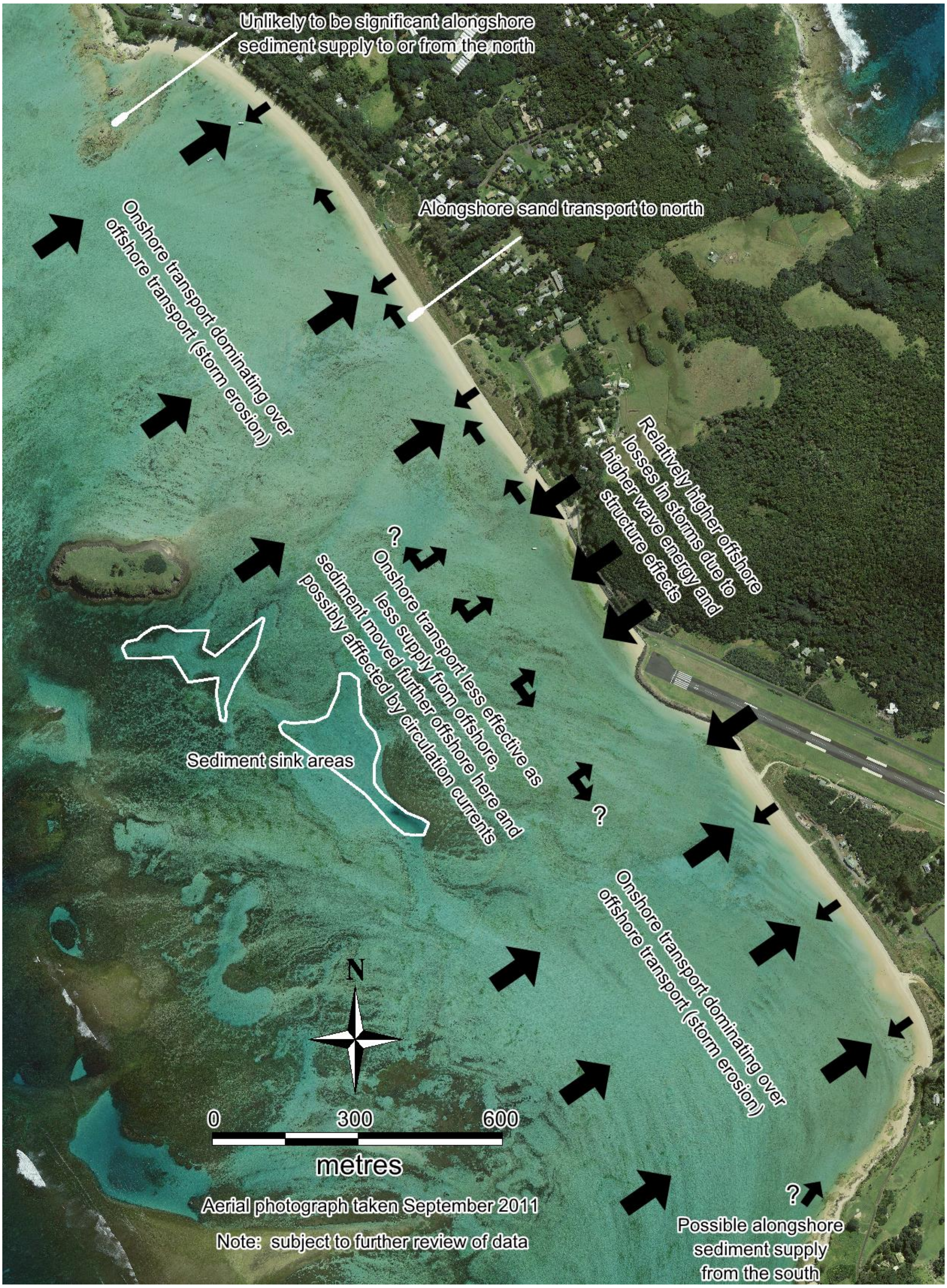

Figure ES2: Preliminary conceptual model of sediment transport processes in Lagoon and at Lagoon Beach and Cobbys Beach

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.

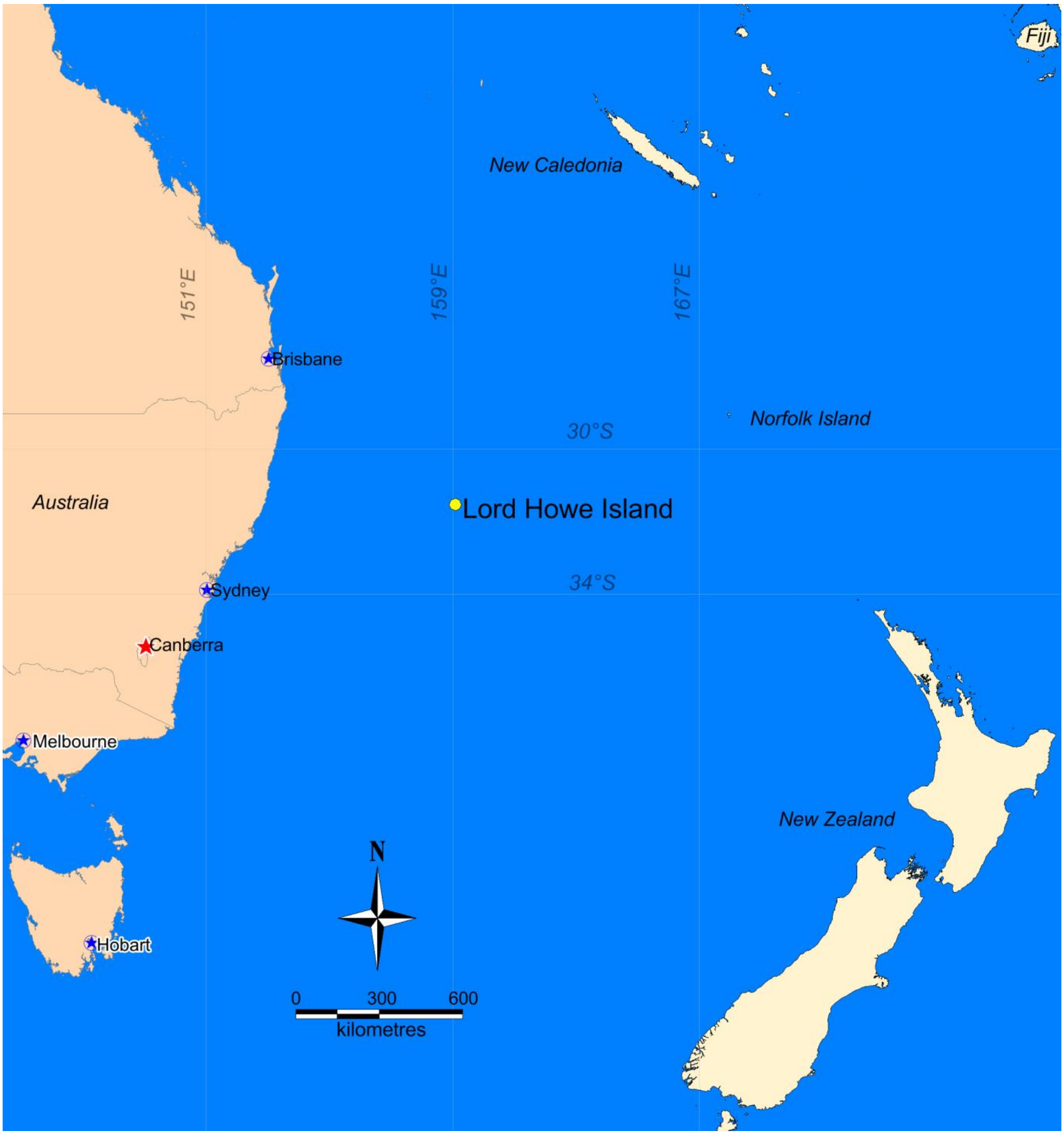

Figure 1: Location of Lord Howe Island in Pacific Ocean

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

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

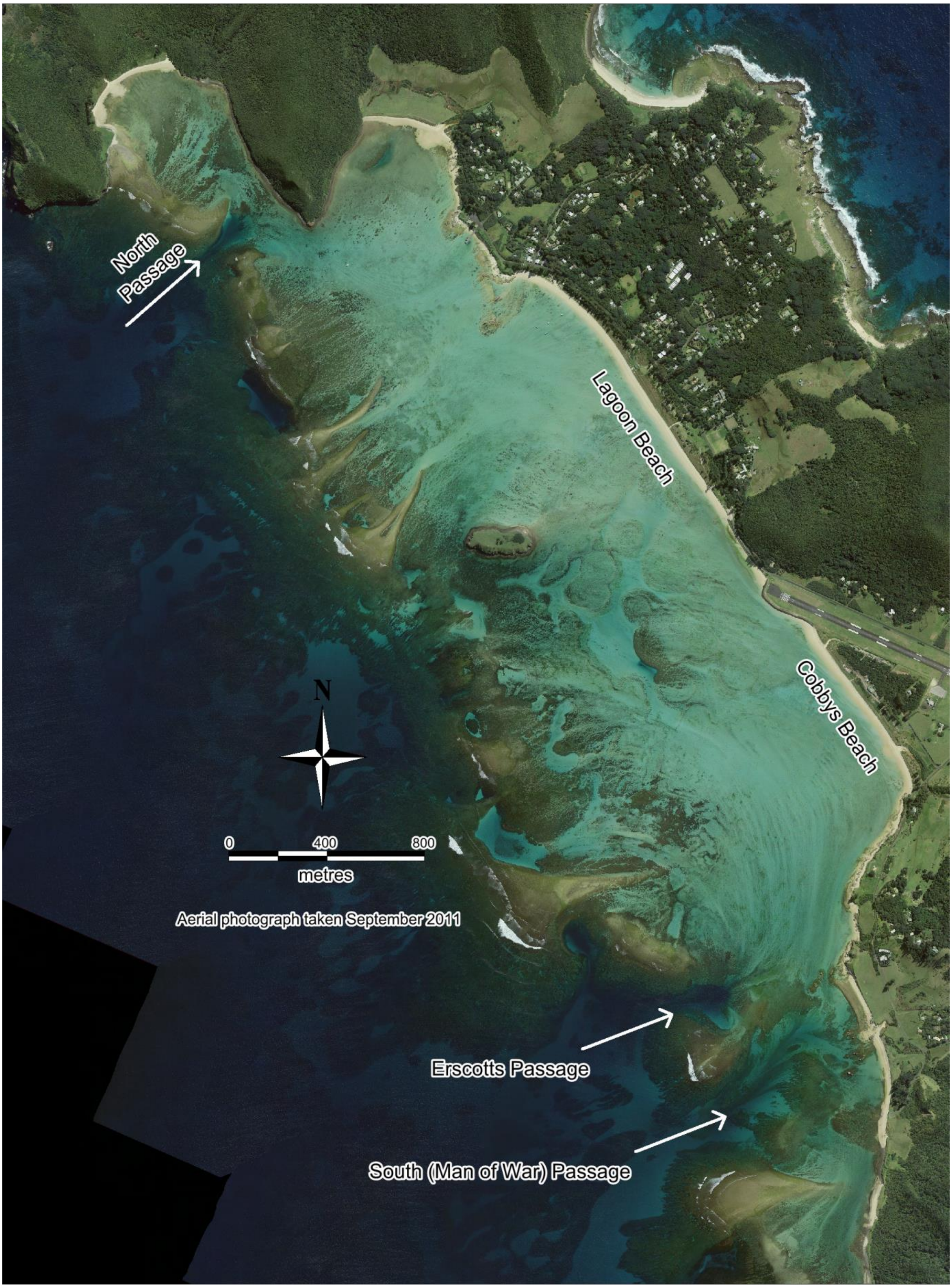

Figure 4: Aerial photograph of Lagoon Beach and Cobbys Beach area at Lord Howe Island

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.

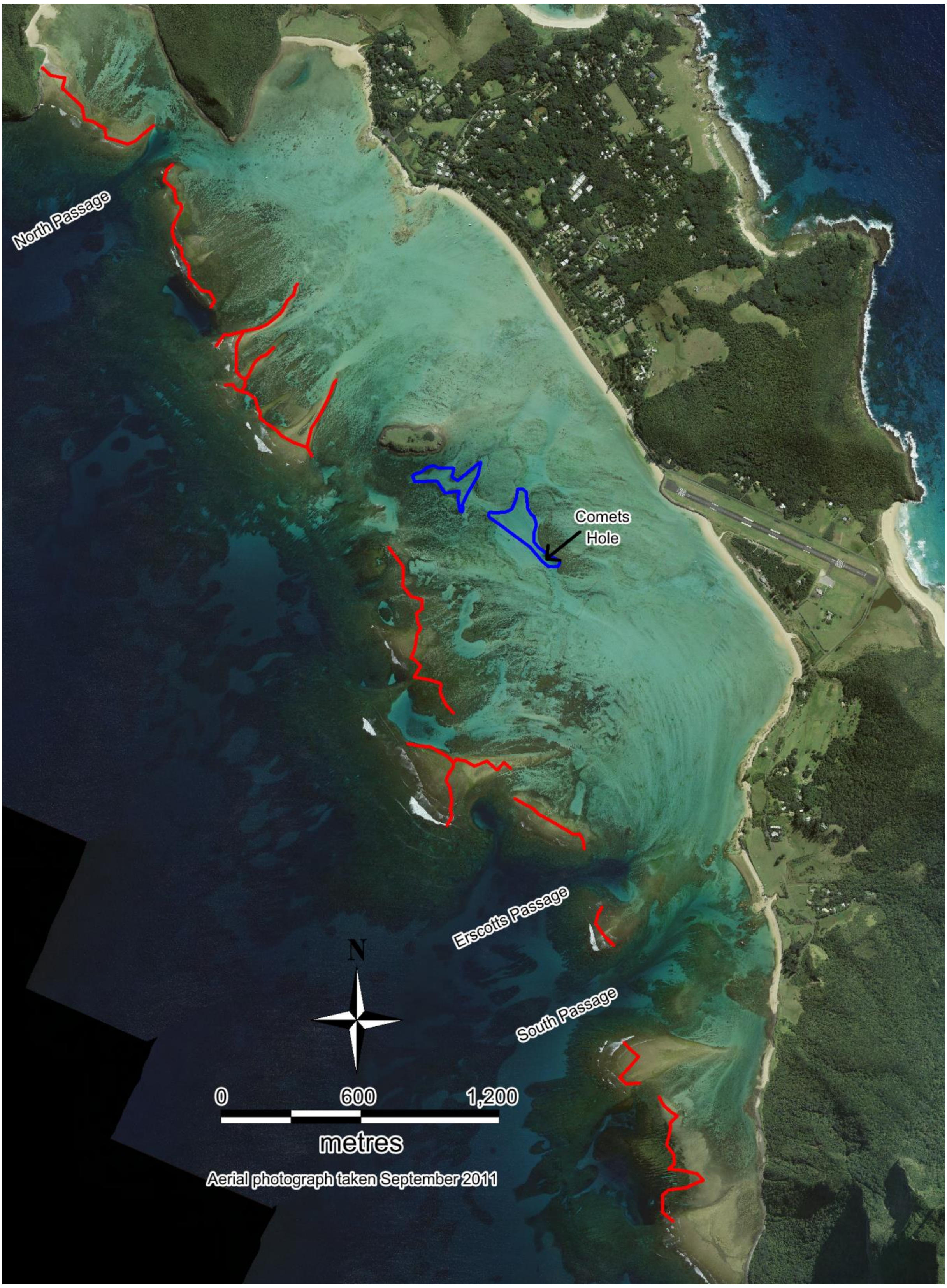

Figure 9: Position of reef crests adjacent to Lagoon (red), and location of relatively deep holes (blue)

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