Review of Coastal Processes and Evaluation of the Impact of the Constructed Groynes along Lady Robinsons Beach, Botany Bay, New South Wales, Australia

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Abstract
Changes in the morphology of Lady Robinsons Beach, Botany Bay, were determined using historical aerial photographs provided by the Rockdale City Council. Human induced changes to the bay, resulting from the construction of the Sydney Airport Parallel Runways and Port Botany, as well as dredging within the bay have altered the wave regime interacting with the beach. These changes cause refracted wave patterns and subsequent longshore sediment transport. Eleven rock rubble groynes were constructed in two separate stages (1997 and 2005) in an attempt to widen and stabilise the beach. The effectiveness of these groynes at maintaining a wide beachfront was determined by observing changes in the morphology of the beach since their construction, using aerial photographs. It was found that while, in many areas, the groynes have been successful at creating a wider beachfront, there are several areas where erosion and accretion is still taking place. Therefore it was concluded that the groynes are not entirely effective at solving the erosion problems experienced on Lady Robinsons Beach. Sediment samples were collected both on and offshore and particle size analysis was undertaken on these samples. There was found to be a significant difference in particle size of sediments on the southern point of the beach where there is a large accumulation of sediment. Analysis suggests that since the construction of the groynes this area has developed into a dune feature. This highlights the significant effects the groynes have had on Lady Robinsons Beach. It is clear that Lady Robinsons Beach has, and is still, undergoing significant morphological changes. It is likely that more protective measures are going to be put in place in order to protect the beach from irreversible damage.

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REVIEW OF COASTAL PROCESSES AND EVALUATION OF THE IMPACT OF THE CONSTRUCTED GROYNES ALONG LADY ROBINSONS BEACH, BOTANY BAY, NEW SOUTH WALES, AUSTRALIA

By

GREGORY FROST

A research report submitted in partial fulfilment of the requirements for the award of the degree of

BACHELOR OF ENVIRONMENTAL SCIENCE HONOURS

ENVIRONMENTAL SCIENCE PROGRAM

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2011
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Abstract
Changes in the morphology of Lady Robinsons Beach, Botany Bay, were determined using historical aerial photographs provided by the Rockdale City Council. Human induced changes to the bay, resulting from the construction of the Sydney Airport Parallel Runways and Port Botany, as well as dredging within the bay have altered the wave regime interacting with the beach. These changes cause refracted wave patterns and subsequent longshore sediment transport. Eleven rock rubble groynes were constructed in two separate stages (1997 and 2005) in an attempt to widen and stabilise the beach. The effectiveness of these groynes at maintaining a wide beachfront was determined by observing changes in the morphology of the beach since their construction, using aerial photographs. It was found that while, in many areas, the groynes have been successful at creating a wider beachfront, there are several areas where erosion and accretion is still taking place. Therefore it was concluded that the groynes are not entirely effective at solving the erosion problems experienced on Lady Robinsons Beach. Sediment samples were collected both on and offshore and particle size analysis was undertaken on these samples. There was found to be a significant difference in particle size of sediments on the southern point of the beach where there is a large accumulation of sediment. Analysis suggests that since the construction of the groynes this area has developed into a dune feature. This highlights the significant effects the groynes have had on Lady Robinsons Beach. It is clear that Lady Robinsons Beach has, and is still, undergoing significant morphological changes. It is likely that more protective measures are going to be put in place in order to protect the beach from irreversible damage.
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1. Introduction

1.1. Coasts: an introduction
Coastal erosion, its causes, effects and possible prevention methods is an important issue in any coastal settlement or region. The ‘coastal zone’ is defined as the land within 5 km of the coast, or sometimes beyond 5 km for low lying areas (Queensland Government Department of Environment and Resource Management 2010). Worldwide these coastlines are approximately 440,000 km long but comprise of less than 1% of the land surface of the earth (Davis Jr & Fitzgerald 2004; Queensland Government Department of Environment and Resource Management 2010). Despite its relatively insignificant size, coastal zones are home to over 50% of the total world’s population (Viles & Spencer 1995; Woodroffe 2002). This statistic is even more pronounced in Australia with 85% of people living within 50 km of the coast line and 25% within 3 km of the ocean (Komar 1998; ABS 2009). This can be seen in Figure 1-1, which graphically represents the distribution of people in Australia.

Worldwide, and particularly Australia’s coastline is used for a wide variety of resources such as fishing (both commercial and recreational), sand mining and residential development (Perry & Taylor 2007). It is also utilised for recreational uses such as water sports, beach recreation and sight-seeing (James 2000). Economic boosts created by these activities are often essential to the survival of a coastal rural or urban centre. It is therefore clear that protection and effective management of Australia’s coastline is of vital importance.

Figure 1-1: A map of Australia showing the population distribution as of the 2006 census. Notice the majority of high density population areas are close to the coast. Source: Australian Bureau of Statistics 2009.
Beaches are an important aspect of the world’s coastal zones for economic and ecological reasons. Beaches consist of unconsolidated sand and/or gravel and/or rocky deposits situated on the shore of a large body of water and make up approximately 40% of the world’s coastline (Bird 2000). Woodroffe (2002 p.248) provides a simpler definition of a beach as “wave-deposited sediment”. Australian beaches are of vital importance to the country for economic reasons. Approximately one-third of all international tourists that visit Sydney will spend time at the beach, which makes effective coastal management an extremely important field in Australia to ensure beaches are protected from ongoing degradation (James 2000, p.497). Beaches are not only important for economic reasons, but also for ecological reasons. Plants, animals and microorganisms heavily rely on a stable coastline to survive (Viles & Spencer 1995). An unstable coastline can result in drastically changed morphology following storm events etc. This can lead to the destruction of important habitats for plants, animals and microorganisms.

1.2. Coastal Processes, Erosion & Littoral Drift

1.2.1. Introduction to Coastal Processes

Coastlines are some of the most dynamic, high energy ecosystems on Earth (Woodroffe 2002). They are constantly evolving, changing shape, receding and expanding. The coastlines that are present today have been acted upon and shaped by processes, such as wind, waves and tides, for millions of years (Woodroffe 2002). The various coastal processes, and in particular the hydrodynamics such as waves and currents, are responsible for the movement of beach sediments. Sediments are continuously being affected by these processes which sorts them into specific size categories from clays all the way to pebbles or cobbles (Komar 1998; Masselink & Hughes 2003). Of these processes it is the waves that have the most pronounced effect of the world’s coastlines and in particular the world’s beaches.

1.2.1.1. Waves

Waves are the principal coastal process acting on the world’s beaches and provide most of the energy which creates nearshore currents resulting in the movement of sediment (Hardisty 1990; Komar 1998; Woodroffe 2002; Masselink & Hughes 2003). In turn, it is this movement of sediment which is responsible for present beach morphology. Waves are moving undulations on the surface of a body of water which result in the transfer of energy but not the net transfer of mass (Woodroffe 2002, p.100). Most oceanic waves form as a result of prolonged transfer of wind energy to the surface of the ocean. Crests of water are then created and are propagated in a downwind direction (Hardisty 1990; Woodroffe 2002).
In terms of sediment transport created by waves and the morphology of beaches, wave refraction is the most important process effecting beaches. This is because it is the refracted waves that create longshore currents resulting in longshore sediment transport. Wave refraction occurs when an oceanic wave approaches the shoreline and crosses bottom contours, meaning, the wave is passing over areas of varying depth. The velocity of a wave is greater in deeper water and therefore as a wave passes regions of varying topography a bend in the wave crest will occur. This process is known as wave refraction (Woodroffe 2002; Masselink & Hughes 2003; Mangor 2004). This bending leads to the wave realigning with the submarine contours and the waves approaching the beach almost parallel to the shoreline (Bird 2000; Mangor 2004; Nielsen, Bonner & Berthot 2011). Wave breaking is an important aspect of coastal processes as it is during the breaking of waves that the potential energy inside the wave is released. This release of energy can result in the formation of nearshore currents and subsequently sediment transport (Masselink & Hughes 2003).

1.2.1.2. Tides

The cause and effect of the periodical rise (flood) and fall (ebb) of the world’s oceans was initially described by Isaac Newton who stated that these tides were caused by the gravitational attraction between the Earth and the Sun and Moon (Bird 1996). He explained that the gravitational attraction from the sun and moon arise from the product of their masses divided by the square of their distance from the earth. Although the sun has a much larger mass then the moon, the close proximity of the moon to the earth means that its gravitational influence is only 0.46 times that of the moon (Pugh 2001). This gravitational attraction causes the water in the oceans to bulge out at the side of the earth facing the moon and the side facing away.

Tides can be considered long waves with a period of 43,000 seconds or 12 hours 25 minutes (Woodroffe 2002). This means that roughly every 12 hours a tide will have risen to its peak, ebbed out, and then risen to its peak again. Basically this time is a wave frequency (Woodroffe 2002). The change of sea level, as a result of tidal movements, results in a much wider nearshore zone. This is because the ebb and flow of the tide will constantly be shifting the zone affected by wave action (Komar 1998). Tidal processes give rise to tidal currents that are at their strongest at the entrances of lagoons or bays, and often within these regions, tides are the major coastal process in play (Masselink & Hughes 2003).

1.2.2. Coastal Erosion

Due to their dynamic nature and the power of the processes acting upon them, the world’s coastlines are constantly undergoing change. Many shorelines can recede and progress due to natural processes. However coastal erosion is a different matter. The Australian Bureau of
Meteorology (2010) defines coastal erosion as the “permanent loss of land along the shoreline”. For the past few decades over 70% of the world’s sandy beaches have been undergoing net erosions (Viles & Spencer 1995, p.75). Coastal erosion, particularly in well developed regions such as towns and cities, can be an extremely expensive problem to fix (Charlier & Meyer 1998).

While there are many natural causes of coastal erosion (such as tsunamis) it is the human induced causes that combine to cause the most economic damage worldwide. Examples of ways that humans can create coastal erosion problems include the dredging of channels causing wave refraction, sand mining, building of mariners or large scale ports and the construction of coastal engineering structures (Charlier & Meyer 1998; Saengsupavanich et al 2008; The Australian Bureau of Meteorology 2010). These human activities can de-stabilise a coastal area resulting in changes to the morphology, often irreparably.

**1.2.2.1. Longshore Currents & Littoral Drift**

Longshore currents are created on a beach when waves approach the beach at an oblique angle. This angle of approach causes wave refraction. Energy is released when the refracted wave breaks in the swash zone of a beach. A current is formed parallel to the beach as a result of a wave breaking at an angle to the shoreline. These currents are called longshore currents and flow in the direction of wave refraction. Sediment brought into suspension as a result of this increased energy is then transported in the direction of the longshore current. These currents move parallel with the shoreline and are the driving force behind littoral drift (McDougal & Hudspeth 1989; Komar 1998; Li & Johns 1998; Woodroffe 2002; Masselink & Hughes 2003; Celikoglu, Yuksel & Kabdash 2004).

Littoral drift is a process that affects many beaches worldwide, particularly beaches that have been altered by human activity such as dredging, land reclamation and port construction (Saengsupavanich et al 2008). Littoral drift defined as the sediment moved along or parallel to a shoreline. The process is formally known as littoral sediment transport or longshore sediment transport (Mangor 2004; Komar 1998). As mentioned above littoral drift is caused by wave action along a beach and the magnitude of it depends on three key characteristics:

i) Wave height and subsequent energy

ii) Sediment grain size and

iii) The angle the waves reach the shoreline (Charlier & Meyer 1998; Mangor 2004;)

It has been determined that waves approaching a beach at an angle of 45° create the optimal conditions for longshore currents to be created and subsequent littoral drift (Gourlay 1982; Bird 1984; Gourlay & Apelt 1985). Once suspended, sediments are affected by the velocity of the
longshore current. Whether or not sediments will stay in suspension is governed by the velocity of the flow and the grain size of the sediment and can be graphically depicted in Figure 1-2 (Woodroffe 2002).

![Figure 1-2: Relationship between sediment entrainment and deposition and particle size and fluid velocity (Woodroffe 2002).](image)

Longshore sediment transport, particularly human induced longshore sediment transport, can induce major erosional patterns on beaches. Depending on the location of the beach these erosional forces may cause major economic problems and be incredibly hard to rectify. Coastal engineering structures such as groynes, sea-walls, offshore breakwaters and beach nourishment programs are commonly needed to help combat the effects of longshore sediment transport. In order to use these engineering techniques initial studies of the beach in question are carried out and an important aspect of these studies is the determination of a beaches sediment budget.

1.2.2.2. **Sediment Budgets**

Often during the study of beaches a sediment budget is created. A sediment budget a measure of the incoming sediments or credits versus the outgoing sediment or debits (Bird 2000). Komar (1998) summarized sediment credits and debits into the following table (Table 1-1):

<table>
<thead>
<tr>
<th>Credits</th>
<th>Debits</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Longshore transport into the area</td>
<td>• Longshore transport out of the area</td>
</tr>
<tr>
<td>• River transport</td>
<td>• Alluvial transport out of the area</td>
</tr>
<tr>
<td>• Sediment derived from sea cliff erosion</td>
<td>• Offshore transport</td>
</tr>
<tr>
<td>• Onshore transport</td>
<td>• Deposition in submarine canyons</td>
</tr>
<tr>
<td>• Biogenous deposition</td>
<td>• Solution and abrasion</td>
</tr>
<tr>
<td>• Hydrogenous deposition</td>
<td>• Mining</td>
</tr>
<tr>
<td>• Alluvial transport</td>
<td></td>
</tr>
<tr>
<td>• Beach nourishment</td>
<td></td>
</tr>
</tbody>
</table>

*Table 1-1: Examples of sediment credits and debits (Komar 1998).*
If the rate of incoming sediment is equal to the outgoing sediment then the beach is stable or in an equilibrium state. Sediment budgets are often determined by undertaking repeated surveying of a particular beach to measure the changes over a period of time (Bird 2000). Results can also be compared with historical aerial photographs (if available) to gain an understanding of the overall change of the beach over an extended period of time. Creating a sediment budget for a beach can be beneficial, according to Komar (1998) because it compels the researcher to take an overall view of the study region and incorporate all possible credits and debits of sediment. Sediment budgets are essential before starting any coastal engineering projects.

1.3. Coastal Engineering

Beaches are an important aspect of the coastal region, particularly in Australia, for economic reasons such as tourism and industrial processes such as sand mining. With tourists often citing beaches as a major attraction of travelling in Australia, it is obviously important that beaches be protected to ensure their ongoing sustainability. However in large urban centres such as Sydney, NSW, often coastal processes are altered as a result of human activity, for example the construction and dredging of a port or harbour, or the building a mariner. This, as mentioned above, can lead to littoral sediment transport resulting in large scale coastal erosion. In order to limit the damage that this can cause several coastal engineering techniques are often employed.

1.3.1. Groynes

Groynes are one of the most common engineering solutions to beaches that are experiencing erosion as a result of longshore sediment transport (Komar 1998; Davis Jr & Fitzgerald 2004). They are normally constructed out of stone or metal, but occasionally timber will be used. They are almost always built perpendicular, or near perpendicular to the shoreline, jutting out into the ocean and basically acting like a dam or sediment trap, trapping the littoral drift (Viles & Spencer 1995; Clark 1996; Charlier & Meyer 1998; Woodroffe 2002; Masselink & Hughes 2003).
Figure 1-3: G2 at Lady Robinsons Beach, Botany Bay, Sydney NSW (Source: Frost 2011). The clear deposition of sand on the right of the groyne shows direction of littoral sediment transport is from right to left (South-North). This groyne is approximately 100 m long and 5 m wide and constructed mainly of basalt rocks of varying size (between 50-150 wide). This groyne was constructed in 2005.

If an extended stretch of beach is experiencing erosion due to longshore sediment transport then often a series of groynes, or groyne field, is built. This is because the construction of a single groyne will trap sediment only in a localised area and the erosion problem will continue along the rest of the beach. Groyne fields are used to create a series of small pocket beaches with the objective of stabilising and widening a beach over a larger area. For groyne fields to be effective they need to be constructed in a certain way. Firstly, the length of the groyne should be approximately 40-60% of the width of the surf zone (Komar 1998; Masselink & Hughes 2003). This ensures that not all the littoral drift is captured by the groyne.

The spacing of the groynes is also important and varies depending on the strength of the longshore currents and the grain size of the littoral drift. The sediment grain size determines how easily and how far it can be transported with the longshore currents. Therefore finer particles are likely to be transported further than coarser particles. Groyne spacing also depends on the length of the groynes. For a sandy beach the ratio between length and spacing may be 1:4. For a more gravely beach, the ratio may be 1:2 (Bruun 1985; Masselink & Hughes 2003). If the groynes are constructed too close together, sediment can be washed offshore rather than helping to stabilise the beaches between the groynes (Charlier & Meyer 1998).

Once a groyne field is constructed they will begin trapping littoral drift. The sediment flowing alongshore will be deposited on the upstream side of the groyne. This is because the groyne is acting as a trap, blocking the path of the sediment transport and therefore forcing it to be deposited here. This creates a build-up of sand and helps to maintain a stable beach. The downdrift side of the groyne, however, is naturally starved of some sediment, and therefore, localised erosion usually
occurs here (Clark 1996; Mangor 2004). A well-designed groyne, once filled with sediment, will allow littoral drift to pass around it and settle further down the beach (on the upstream side of the next groyne). Therefore the area between two groynes should replicate a relatively stable mini or pocket beach (Komar 1998). When observing aerial photographs of a groyne the build-up of sediment on one side is usually easily observable (see Figure 1-4).

![Figure 1-4: Aerial photograph of G2 at Lady Robinson Beach showing clear build-up of sediment on the down-drift (southern) side. Source: nearmap.com (2011). The southern side of this groyne is the zone of deposition and the northern side is a zone of erosion. From this photograph it can be concluded that the direction of longshore sediment transport is from bottom to top (South to North).](image)

### 1.3.1.1. Problems Associated with Groynes

Despite often being effective at trapping sediment and stabilising a beach in a localised area, groynes often have some negative impacts on the surrounding areas (Valiela 2006). They also do not solve the longshore sediment problem completely because the coastal processes causing sediment transport are still in play (Chapman et al 1982). One problem consistently associated with groynes is the creation of adjacent rip currents (Masselink & Hughes 2003; Mangor 2004; Pattiaratchi et al 2009). Rip currents are formed when water, brought to the shore as waves, seeks to return back out to sea. Rip currents often form adjacent to coastal structures such as headlands, rock platforms or groynes. This is because narrow channels are often formed alongside these structures which allow a passage for the water to easily flow out to sea. Many groynes may experience rip currents on both the upstream and lee-side of groynes which can be hazardous to recreational users who may be dragged offshore (Pattiaratchi et al 2009). In Australia up to 25% of beach drownings are attributed to rip currents (Surf Life Saving Australia 2010).
1.3.1.2. Case Study: Cottesloe Beach and City Beach in Western Australia

Pattiaratchi et al (2009) undertook a study of groynes at Cottesloe and City Beaches in Western Australia, focusing on the nearshore circulation patterns in the lee of the groynes. The study was carried out during a period of moderate swell conditions. Waves were approaching the groynes from the south west. Surfzone ‘drifters’ were used to monitor the flow of the water on the lee side of the groynes. They found that water on the lee side of the groyne was re-circulated as a longshore current towards the groyne and then forced out to offshore creating a rip current. This water was then circulated back again meaning that the water was constantly circulating (see Figure 1-5).

Previous studies by Komar (1998, cited in Pattiaratchi et al 2009) had described the creation of rip currents on the upstream side of groynes but this study found that there is significant re-circulation of water in the lee of groynes creating rip currents.

Another commonly reported negative impact of groyne fields is that they starve the supply of sediment to downdrift regions beyond the reach of the groyne field (Chapman et al 1982; Komar 1998; Charlier & Meyer 1998; Mangor 2004). If too much of the littoral drift along a section of coastline is being trapped by a groyne field then there will be an obvious lack of supply to those areas further downdrift from the fields. This can have negative effects not only aesthetically (due to the loss of beach front/sediment) but also on beaches as a potential habitat for plants and animals (Walker, Schlacher & Thompson 2008).
1.3.2. Offshore Breakwaters

Also known as detached breakwaters, offshore breakwaters are another coastal engineering structure that can be used to protect beaches from coastal erosion. Unlike groynes, and as the name implies, they are built offshore, run parallel or near-parallel with the shoreline, and are designed to reduce the wave and current energy reaching the beach (Viles & Spencer 1995; Clark 1996; Charlier & Meyer 1998; Komar 1998; Masselink & Hughes 2003; Birben, Özölçer, Karasu & Kömürcü 2007; Sane, Yamagishi, Tateishi & Yamagishi 2007). The wave energy is reduced on the shoreward side of the breakwater because most of the energy is taken up on the seaward side. Like groynes they are normally built in groups of more than one to help protect a long stretch of beach (Birben et al 2007).

Offshore breakwaters are generally between 25-100 m long and are constructed just outside of the surf zone. They are usually built with their tops protruding from the water surface however if suitable conditions are present, (e.g. relatively small tidal range), then they can be constructed to be just below the surface of the water. This can improve the aesthetics of the beach but it makes the construction of the breakwaters more expensive (Bird 1996).

The construction of offshore breakwaters can affect the shoreline in one of three ways (see Figure 1-6);

i.) The development of a tombolo (sand bar) that actually attaches to the structure.

ii.) The formation of a salient on the lee side of the breakwater. This doesn’t attach to the structure.

iii.) Little or no modification to the existing shoreline (Komar 1998; Masselink & Hughes 2003).

![Figure 1-6: Schematic diagram of detached breakwaters characterizing formation of accretionary features and downcoast erosion pattern](image)

*Figure 1-6: Schematic diagram of detached breakwaters characterizing formation of accretionary features and downcoast erosion pattern (Sane et al 2007).*

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The design of offshore breakwaters determines what sort of morphological response from the shoreline there will be. For example relatively long breakwaters that are constructed considerably close to the shoreline usually promote the formation of tombolos (Masselink & Hughes 2003). As a general rule the shorter the gap the more sediment will build up behind a breakwater hence increasing the chance of a tombolo forming (Sane et al 2007).

Offshore breakwaters can provide an effective alternative to groynes because they can still allow longshore sediment transport to occur which can help to ensure that downstream coastlines aren’t starved of sediment inflow and therefore do not experience severe erosion (Clark 1996). They also do not deflect sediments offshore. The beach areas directly behind the breakwaters are generally built up because the amount of wave energy able to reach the shore has been reduced, which lowers the strength of longshore currents and thus lowers longshore sediment transport (Komar 1998). This causes the build-up and stabilisation of the beach, and reduces erosional impacts acting on the coast while still allowing some longshore sediment transport.

1.3.2.1. Problems Associated with Offshore Breakwaters

The main disadvantage of using offshore breakwaters for coastal protection is their relatively high cost and frequent maintenance requirements (Komar 1998; Masselink & Hughes 2003; Sane et al 2007). The requirement for maintenance is due to the high energy environments that many offshore breakwaters are constructed in. Another key disadvantage of breakwaters can be the formation of a tombolo which can completely block longshore sediment transport leading to downstream starvation of sediment and subsequent erosion. This can be avoided by constructing slightly submerged breakwaters which allow sufficient wave energy to pass to prevent tombolo formation or by widening the gap between breakwaters (Sane et al 2007).

1.3.3. Beach Nourishment

Since beach nourishment was first used as a solution to coastal erosion in 1922 on Coney Island, New York, it has become a widely used technique throughout the world (Bird 1996). Unlike other techniques that require the construction of ‘hard’ structures beach nourishment simply involves the dumping of sand or gravel onto a beach to widen the beach and help to protect the shoreline from damages caused during large storm events (Bird 2000; Castelle et al 2009; Fanini et al 2009). One of the most famous cases of beach nourishment occurred between 1976 and 1980 on Miami Beach, Florida. Over this period US$60,000,000 was spent dumping 13,000,000m$^3$ of sand to help protect the severely eroded beach that is vital for tourism in the region (Woodroffe 2002). Beach nourishment is often coupled with the construction of a ‘hard’ structure such as a breakwater or groyne because the nourishment does not stop the forces causing erosion (Bird 2000).
1.3.3.1. Case Study: Coolangatta Bay, Gold Coast, Australia
During the 1960’s the two breakwaters at the mouth of the Tweed River in the Gold Coast, Queensland Australia were extended in order to provide a safer entrance/exit to the open ocean. These extensions, however, cut off important longshore sediment transport that was sourcing the surrounding beaches of Coolangatta Bay. This resulted in severe erosion of Rainbow Bay, Coolangatta Beach and Kirra Beach.

Figure 1-7: Aerial Photograph of the Coolangatta bay area 1998 (Castelle et al 2009).

In order to rectify the erosion problem created two nourishment projects were carried out.

1.) 1989-1990: nourishment of the nearshore and upper beach of Kirra Beach. 400,000 m$^3$ of sand was dumped in water depth between 6 and 9m for the nearshore and 3,200,000 m$^3$ of sand was dumped on the beach.

2.) 1995-present: Tweed River Entrance Sand Bypassing Project (TRESBP) involved constructing a permanent sand bypassing system that pumped sand to five different locations in the region (Castelle et al 2009).

According to Bird (1996), in 1996 the Gold Coast region generated Au $100 million a year through tourism and the continued nourishment of the beach costs Au $10 million. Therefore it is seen as a viable option.

1.3.3.2. Problems Associated with Beach Nourishment
Undertaking a beach nourishment program does not solve a coastal erosion problem. The forces acting on the beach and causing the loss of sediment will still be in play unless other techniques are used. Therefore it is common for a nourished beach to require ‘renourishment’ or ‘replenishing’. This involves dumping more sand into the region to ensure that the beach is not eroded away (Bird
This is obviously going to be costly over time and it must be determined if this is economically viable (note case study on Coolangatta Bay).

The sourcing and transportation of the sediment can also be difficult and expensive. It is necessary to find suitable sediment for a nourishment project, with grain size needing to be similar (if not a little more coarse) to that of the original beach (Woodroffe 2002). Often the sediment is sourced from areas away from the beach, such as a desert, and therefore transportation costs can be high.

The main drawback of beach nourishment as a solution to coastal erosion is that it is not a permanent solution. It does not alter the coastal processes acting on a beach and therefore it usually requires ongoing renourishment.

1.4. Beach Sediments

The study of coastal sediments is an extremely important topic in regards to coastline research, and especially in the study of beaches. Beaches consist of unconsolidated sand and/or gravel deposits situated on the shore of a large body of water and as such the study of sediments is vitally important. There are several commonly used categories used during the sedimentological studies of coastlines and beaches including grain size, grain shape, and grain sorting.

1.4.1. Particle Size

One of the most commonly used characteristics of sediments is their particle size. Depending on the size of the particles they can simply be measured using some sort of handheld device. However, for smaller grain sizes such as sands, clays and silts measurements are normally undertaken using a sieve technique (Blatt, Middleton & Murray 1980). Grains are often measured according to their axes; longest (L), intermediate (I), and shortest (S) with the ‘I’ and ‘S’ axes measured at right angles to the L axis (Masselink & Hughes 2003).

Once the grain size has been determined, either using handheld techniques, or by a mechanical particle size analysis technology it is necessary to classify the sediment into a particular category. The most widely used sediment particle size classification scheme is the ‘Udden-Wentworth Scheme’ (Garde & Ranga Raju 1977; Masselink & Hughes 2003; Nichols 2009). This scheme uses a negative logarithmic to the base 2 which is called a phi scale (Woodroffe 2002). Using this technique sediment can be placed into a specific category ranging from boulders down to clay (see Table 1-2).
Table 1-2: The Udden-Wentworth Grain Size Classification Scheme (Source: Blatt et al 1980).

<table>
<thead>
<tr>
<th>Diameter (mm)</th>
<th>Wentworth Classes</th>
<th>Phi (Φ) Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;256</td>
<td>Boulder</td>
<td>–8</td>
</tr>
<tr>
<td>&gt;64</td>
<td>Cobble</td>
<td>–6</td>
</tr>
<tr>
<td>&gt;4</td>
<td>Pebble</td>
<td>–2</td>
</tr>
<tr>
<td>&gt;2</td>
<td>Granule</td>
<td>–1</td>
</tr>
<tr>
<td>&gt;1</td>
<td>Very coarse sand</td>
<td>0</td>
</tr>
<tr>
<td>&gt;0.5</td>
<td>Coarse sand</td>
<td>1</td>
</tr>
<tr>
<td>&gt;0.25</td>
<td>Medium sand</td>
<td>2</td>
</tr>
<tr>
<td>&gt;0.125</td>
<td>Fine sand</td>
<td>3</td>
</tr>
<tr>
<td>&gt;0.0625</td>
<td>Very fine sand</td>
<td>4</td>
</tr>
<tr>
<td>&gt;0.0312</td>
<td>Coarse silt</td>
<td>5</td>
</tr>
<tr>
<td>&gt;0.0156</td>
<td>Medium silt</td>
<td>6</td>
</tr>
<tr>
<td>&gt;0.00781</td>
<td>Fine silt</td>
<td>7</td>
</tr>
<tr>
<td>&gt;0.00391</td>
<td>Very fine silt</td>
<td>8</td>
</tr>
<tr>
<td>&lt;0.00391</td>
<td>Clay</td>
<td>&gt;8</td>
</tr>
</tbody>
</table>

A particle size analysis determines approximately the percentage of sediments in a sample that fit into the categories of the Udden-Wentworth Scheme. Results from particle size analysis are generally plotted in one of three ways;

1.) A histogram of the weight percentage of each of the size fractions (e.g. sand, silt, clay etc)
2.) A frequency curve, or
3.) A cumulative frequency curve (Nichols 2009).

Coarse grains are plotted on the left and these graphical displays of the results allow the skewness of the data to be observed. A negatively skewed histogram implies coarse grains whereas a positively skewed histogram suggests finer grains (Masselink & Hughes 2003; Nichols 2009). Kurtosis is also observable which is whether or not the graph has a sharp and high peak, or a flatter and long peak (Nichols 2009).

1.4.2. Grain Sorting

The results of a particle size analysis give a value for the mean of the sediment sample being tested. This means the average particle size of the sample is calculated. Possibly more important however is the standard deviation that is calculated which represents the sediment sorting. A well sorted sediment sample will have similar particle sizes throughout (Komar 1998, Masselink & Hughes 2003) i.e. the particles will fall mainly into one category on the Udden-Wentworth Scheme (Nichols 2009).

The sorting of a sample can be observed once the results of a particle size analysis have been plotted graphically. A steep peak in the histogram suggests a well sorted sample as does a steep rise in a frequency curve (Blatt et al 1980).
1.4.3. **Particle Shape**

This is a complex characteristic of sediments and is often difficult to describe. Blatt *et al* (1980) describe four main aspects of shape;

1.) Surface texture: including aspects that are so small they appear not to affect the overall grain shape.
2.) Roundness: the sharpness of the edges and corners of the grain. Ranges from well-rounded to very-angular. Roundness is caused by abrasion during sediment transport (Nichols 2009).
3.) Sphericity: how close to a sphere the grain is. This in a feature that is inherited from the original weathering of the sediment source (Nichols 2009).
4.) Form: a classification of a grains shape depending on the above characteristics.

Often roundness and sphericity are determined together using charts such as Table 1-3.

Table 1-3: A table displaying varying roundness and sphericity of grains (Source: Beehag 2000).

<table>
<thead>
<tr>
<th></th>
<th>High Sphericity</th>
<th>Medium Sphericity</th>
<th>Low Sphericity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Angular</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Angular</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sub-Angular</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sub-Rounded</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rounded</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Well Rounded</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1.4.4. **Depositional Environment**

The analysis of sediment particle size, sorting, and shape can sometimes help to determine the depositional environment into which the sediments settled (Blatt *et al* 1980; Hatfield, Cioppa & Trenhaile 2010) and also the past geomorphology of the region (Woodroffe 2002). For example the sorting of a sediment can be a characteristic of the environment of deposition. Nichols (2009) states that glacial sediments are generally very poorly sorted, river sediments are usually moderately sorted and beach or aeolian sediments are usually well sorted. Sediments on beaches are usually well sorted because they are continually reworked and redeposited because of repeated wave action (Masselink & Hughes 2003). As a general rule the more reworking sediments go through, the better their sorting is.

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Beaches may also show a parallel grading is sediment size. The coarsest grains are found on the shoreline in the swash zone or wave zone. As previously mentioned waves provide the majority of the energy to a beach and therefore it is in the wave zone that the most energy is dispelled. Moving back from the wave zone, parallel to the shoreline the mean grain size decreases as the effect of wave action decreases (Komar 1998). This grading can also occur laterally along a beach due to the effect of longshore currents. Finer particles will travel further along the shoreline then coarser particles (see Figure 1-2) leading to the beach become finer downstream (Komar 1998).

While it is not always possible to make conclusions on depositional environments based on the study of the sediments present, it is generally accepted that sediments of a beach environment differ from others such as a river environment (Blatt et al 1980). Komar (1998) claims that there are three factors that determine the mean grain size of sediments found on beaches;

1.) The sediment source
2.) The wave energy, and
3.) The offshore slope of the beach.

Wave energy, as mentioned above, has a great effect on the sediments of a beach. As a general rule the higher the wave energy acting on a beach the coarser the sediment will be. This is because the finer particles are often resuspended and carried either offshore or parallel to the shoreline (Masselink & Hughes 2003). Because of this, beach sediments are often negatively skewed, meaning there is an excess of coarse grains (Blatt et al 1980; Woodroffe 2002).

1.5. The History of Botany Bay

The founding of Botany Bay is of important cultural significance to Australian history. It was at Botany Bay, on Sunday 29th April 1770, that Captain James Cook first landed on the shores of Australia. This was the first European landing on the East Coast of Australia. The bay was named 'Botany Bay' because of the rich abundance of plant and animal life present there at the time (Fitzgerald 1998). Although this was not the official settlement site, which was at Sydney Cove, Botany Bay is often claimed to be the birthplace of European Australia (Kingston 2006). Thus the Post-European settlement cultural significance of the Botany Bay area cannot be understated.

1.5.1. Physical Characteristics of Botany Bay

Botany Bay is a marine estuary system, situated approximately 12 km south of present day Sydney. The Cooks River flows into the bay in the north-west and the Georges River enters the bay in the South-West (Jones 1981; Hann 1986; Albani& Rickwood 1998). The bay has a relatively narrow opening to the Tasman Sea (approximately 1.1 km) which is flanked by large sandstone headlands.
(Bryant 1980; Trindade et al 1993; Albani & Rickwood 1998). Lady Robinsons Beach makes up a 7 km stretch on the western edge of the bay. The beach runs from the mouth of the Cooks River (in the north) to the Georges River (in the south) (Hann 1986; Sydney Ports Corporation 1995). The bay has a surface area of approximately 32 km² with a maximum east-west distance of 8 km and a north-south distance of around 7 km (Hann 1986). Hann (1986) also states that the bay displays shallow water depths of less than 10 m in most areas apart from the entrance to the open ocean and near the dredged areas adjacent to the airport.

The bay has been significantly developed since the arrival of Europeans and particularly in the 20th Century which has drastically changes not only the physical characteristics of the bay but also the interaction of coastal processes within the bay.

1.5.2. Climatic Conditions

Geeves & Jervis (1954) quote Captain Cook in their book Rockdale: Its Beginning and Development regarding Botany Bay; “We discovered a bay which appeared to be tolerably well sheltered from all winds, into which I resolved to go with the ship.”

The relative sheltered nature of the bay is mainly due to the narrow opening into the Tasman Sea, which is only 1.1 km wide. Hann (1986 p.104) describes Botany Bay as periodically experiencing vigorous wave activity which is due to the high-energy wave climate that is a common characteristic of the south-eastern coast of Australia. It is this wave activity that is responsible for the majority of sediment movement along Lady Robinsons Beach.

Sydney’s average annual temperatures and rainfalls are displayed in Figure 1-8.

![SYDNEY AIRPORT AMO](image)

Figure 1-8: The average annual temperatures and precipitation from the Sydney Airport weather station (Source: Weather Zone 2011). Recordings began here in 1929.

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1.5.2.1. Wave Climate & Storms

Detailed wave data has been recorded for areas offshore Botany Bay since April 1971 (Shand et al 2011). This data is recorded at depths of 200m (Bryant 1980). According to Lord & Kulmar (2000) average offshore significant wave height is between 1.5-1.6 m for the NSW coast with an average period of 9.4-9.7 s. A summary of height, period and direction of waves along the Sydney Coastline is outlined in Figure 1-9. The Botany Bay offshore wave buoys show that the significant wave height offshore of Botany Bay is approximately 1.5 m (Bryant 1980; Trindade et al 1993).

![Graphical representations of the height, period and direction of waves along the coastline of Sydney (Source: Bryant 1980).](image)

Figure 1-9: Graphical representations of the height, period and direction of waves along the coastline of Sydney (Source: Bryant 1980).

Figure 1-10 displays the hourly significant wave height exceedance for various locations along the East Coast of Australia including Botany Bay. The graph shows that the median (50%) exceedance for Botany Bay is around 1.5m which supports Bryant’s (1980) claim that the average wave height of the bay is approximately 1.5 m. During storms however these wave heights are often significantly exceeded. Shrand et al (2011) summarised the frequency of storms, their duration and wave mean and maximum heights in Table 1-4.
Storms can have significant impacts on the sediment budgets of beaches and can often cause irreparable damage (Bryant 1980). According to Bryant and Kidd 1975; Foster et al 1975 (cited in Bryant 1980) a severe storm in May 1974 severely eroded areas of Botany Bay but did not significantly affect Lady Robinsons Beach.

1.5.3. Geological Setting of Botany Bay
Botany Bay exists as part of a minor structural depression known as the Botany Basin, which is situated within the Permo-Triassic Sydney Basin (Haan 1986). The Permo-Triassic Basin is a sedimentary basin that covers 64,000km$^2$ and was formed in the Early Permian (Geosciences Australia 2008).
Exposed rocks layers are limited in the Botany Bay region, however, the Triassic Hawkesbury Sandstone can be observed on the headlands marking the entrance to the bay (Griffin 1963 cited in Albani& Rickwood 1998). This sandstone unit is overlain by the Triassic Wianamatta Group Shales which outcrops to the south-west of Botany Bay (Albani& Rickwood 1998).

The Botany Basin has been infilled with thick sequences of unconsolidated sediments which are Quaternary in age. These sediments were deposited as a result of fluctuations in sea level as a result of glacio-eustatic activity and are up to 90m thick (Haan 1986). Despite the Cooks and Georges Rivers both draining into Botany Bay Haan (1986) and Albani & Rickwood (1998) both state that the majority of the sediment found in the Botany Basin is marine in origin and not derived from modern fluvial processes.

1.5.3.1. Sediment Stratigraphy

According to Haan (1986) and Albani & Rickwood (1998) the unconsolidated sediments present in Botany Bay can be categorised into 4 distinctive layers or units. These layers are displayed in a simple stratigraphic column (see Figure 1-11).

![Figure 1-11: A simple stratigraphic profile summarising the four layers of unconsolidated sediments found in Botany Bay by Haan (1986) and Albani & Rickwood (1998).]
1.5.4. Human Developments of Botany Bay

Since it was first discovered by Europeans in 1770, Botany Bay and its surrounding areas have been significantly altered due to human developments. The Sydney International Airport and Port Botany have both been constructed inside Botany Bay. These required significant modifications to the bay. The resultant changes to Botany Bay’s physical characteristics have had impacts on the wave patterns inside the bay and subsequent longshore sediment transport on Lady Robinsons Beach.

1.5.4.1. Sydney Airport Development History

The Sydney Airport, also known as Kingsford-Smith Airport, is one of the oldest continuously operated airports in the world. The first airplane took off from the present day site in 1911 but it was not until 1920 that the site was officially declared an aerodrome after W.B. Love leased the area and built an aircraft manufacturing facility (Sydney Airport 2010). This new facility was dubbed the ‘Mascot Aerodrome’.

Significant development took place at the airport during the late 1930’s and early 1940’s due to increased military demand required during World War II. The first significant physical change to Botany Bay due to the airport came shortly after WWII when the natural path of the Cooks River mouth was diverted to allow the construction of two new runways (Fitzgerald 1998). Figure 1-12 shows the significant physical change that this had on the northern end of the bay. One of these runways, known colloquially as the ‘Main North-South Runway’, was extended in 1968 to accommodate larger jet aircraft. Another extension was completed in 1972 when the runway reached its current length of 3962 m (Sydney Airport 2010). Figure 1-13 shows the layout of the Sydney International Airport runways.

![Figure 1-12: Left; an aerial photograph showing the original entrance of the Cooks River to Botany Bay (Source: Rockdale City Council 1943), Right; an aerial photograph showing the human constructed entrance of the Cooks River to Botany Bay and the original North-South Runway (Source: Rockdale City Council 1977).]
A third runway running parallel to the East of the Main North-South Runway (see Figure 1-13) was completed and opened in 1994. The construction of the parallel runways of the Sydney International Airport required significant changes to be made to the bay mostly in the form of dredging and reclamation.

1.5.4.2. **Port Botany**

Port Botany is located on the North-Eastern edge of Botany Bay (see Figure 1-13) and serves as one of the major trade import points in Australia (Sydney Ports 2011). Similar to the runway construction at the airport, Port Botany required significant dredging and reclamation in the construction of the docks which are dredged to approximately 15 m deep (Fitzgerald 1998; Sydney Ports 2011). A major extension to Port Botany has been taking place since 2008 which involves the construction of a third berthing dock and terminal. This is being undertaken in response to the continued increase in imports to Sydney.
1.5.5. Dredging & Land Reclamation in Botany Bay

One of the major ongoing human impacts occurring in Botany Bay is the large scale dredging and land reclamation events being undertaken to allow construction of structures such as berthing docks and runways. Dredging is defined as the deepening of waterways by digging and gathering up material from the bottom (Barbosa & Almeida 2001; Davis Jr & Fitzgerald 2004). It is commonly used in the development of harbours, ports, channels, docks or any water that may need deepening for some reason (Sydney Ports Corporation 2009). Dredging for constructional purposes is often undertaken in combination with land reclamation. Land reclamation is the infilling of a body of water with earth (Fitzgerald 1998). It has been used throughout the history of Botany Bay most notably in the construction of the parallel runways for the Sydney International Airport, and in the development (and current expansion) of Port Botany.

According to Jones (1981) up until 1981 550 ha of Botany Bay had been dredged and 140 ha of land reclaimed equating to an area approximately equivalent to 15% of the bay’s total area. This dredging and reclamation took place during the construction of the main north-south runway and the construction of Port Botany. Fitzgerald (1998) claims that 60 million tonnes of sand had been dredged with approximately 50% (30 million tonnes) of this being used in the reclamation of land for the third runway constructed in the early 90’s. Further to these historic dredging and reclamation events, the current expansion of Port Botany is to involve the reclamation of 60 ha of land using 7.8 million m$^3$ of dredged sediment (Sydney Ports Corporation 2009; Sydney Ports 2011). Maps displaying the specific areas have proved difficult to obtain, however a map of the dredging areas up until 1976 is provided by Jones (1981) (see Figure 1-14).

It is clear that Botany Bay has undergone substantial human induced changes from the 20th century onwards and that the infrastructure located at Botany Bay has had a significant impact on the original nature of the bay.
1.5.6. Erosion Problems on Lady Robinsons Beach

Lady Robinsons Beach, which forms the Western edge of Botany Bay, has been affected by significant erosional patterns in the last 40 years. It is generally accepted that the changed morphology of the beach is due, or at least partly due, to the human developments that have taken place in the bay from the 20th century onwards (Jones 1981; Dames & Moore Pty Ltd 1995; Fitzgerald 1998; Connell Wagner 1999; Sydney Ports Corporation 2002; Aijaz & Treloar 2003).

As previously mentioned, longshore sediment transport is caused by refracted wave patterns. The wave regime inside Botany Bay has been altered since the construction of the Parallel Runways of the Sydney Airport, and the building of Port Botany. The dredging and land reclamation associated with these activities has changed the bathymetry of the bay resulting in waves being refracted before reaching Lady Robinsons Beach and created longshore currents and subsequent longshore sediment transport (Jones 1981; Chapman et al 1982; Trindade et al 1993; Aijaz & Treloar 2003).
An Environmental Impact Statement composed by Dames & Moore Pty Ltd (1995) for the Sydney Ports Corporation stated that of the 6,000 m³ per year of erosion predicted to occur on Lady Robinsons Beach:

- 53% would have occurred naturally.
- 9% was due to the impact of the original North-South Runway.
- 26% was due to port related dredging and reclamation.
- 12% was due to estimated final configuration of the parallel runway dredging and reclamation.

These estimations do not include the extension currently taking place at Port Botany however it can be concluded that human related impacts to Botany Bay have had a major effect on the sediment transport patterns of Lady Robinsons Beach. Studies have shown that there is a point of zero transport (null point) located at approximately Pasadena Street, between G3 and G4 (see figure... do this after the map showing the null point has been fixed) (Aijaz & Treloar 2003). The beach area to the north of this is affected by northward longshore sediment transport and the beach south of this is affected by southward longshore sediment transport.

1.5.7. Restoration Work
Connell Wagner (1999) summarised the restoration works that had been undertaken on Lady Robinsons Beach in the following table (Table 1-5).

Table 1-5: Historical restoration works undertaken on Lady Robinsons Beach.

<table>
<thead>
<tr>
<th>Year(s)</th>
<th>Restoration Work</th>
</tr>
</thead>
<tbody>
<tr>
<td>1974</td>
<td>115,000 m³ of sand renourishment between Ramsgate Road and Dolls Point.</td>
</tr>
<tr>
<td>1976</td>
<td>Seawall restoration between Russell Avenue and Dolls Point Baths.</td>
</tr>
<tr>
<td>1977</td>
<td>Transfer of 4,000 m³ of sand from Dolls Point to Ida Street.</td>
</tr>
<tr>
<td>1978-1980</td>
<td>Construction of Florence Street Drain, transfer of 35,000 m³ of sand from Dolls Point to Ida Street.</td>
</tr>
<tr>
<td>1984</td>
<td>Transfer of sand from Sandringham Bay to Ida Street and between Florence Street and Ramsgate Baths.</td>
</tr>
<tr>
<td>1986</td>
<td>Transfer of sand from Sandringham Bay to Ida Street (4,000 m³), between Culver and Scarborough Streets (10,000 m³) and between Florence Street and Ramsgate Road (8,000 m³).</td>
</tr>
</tbody>
</table>
1.5.7.1. Groynes
In response to the erosion occurring on Lady Robinsons Beach two groyne fields have been constructed. The first of these fields consisted of six rock rubble and two concrete panel groynes which were constructed along the Southern end of the beach in 1997 (Connell Wagner 1999; Aijaz & Treloar 2003). These groynes were placed South of Florence Street and were coupled 145,000 m$^3$ of beach renourishment. Another groyne field, consisting of five rock rubble groynes, was completed in 2005 between Florence Street and Solander Street and was coupled with 305,000 m$^3$ of sand renourishment. The groynes were constructed in an attempt to widen the beachfront of Lady Robinsons Beach to help protect it as a recreational area. Prior to groyne construction the beach was in danger of being eroded to an irreparable level. It is estimated by Connell Wagner (1999) that the region will require sand renourishment approximately every 10 years to ensure the ongoing stability of the beach.
2. Study Area

2.1. Map of Botany Bay in its national context

Figure 2-1: The Botany Bay region in its national context.
2.2. **Lady Robinsons Beach**

![Lady Robinsons Beach](nearmap.com 2011)

*Figure 2-2: Lady Robinsons Beach, Botany Bay, NSW Australia (source: nearmap.com 2011).*
2.3. Lady Robinsons Beach- groyne fields

Figure 2-3: The groynes on Lady Robinsons Beach, labelled for reference in this report (source: nearmap.com 2011)
2.4. Lady Robinsons Beach- longshore sediment transport

Figure 2-4: A map of Lady Robinsons Beach displaying the null point (red line) and subsequent direction of longshore sediment transport (yellow arrows) (source: nearmap.com 2011).
3. Methods and Equipment

3.1. Sediment Sample Collection

Initial offshore field work was carried out on Tuesday May 17th at Lady Robinsons Beach. This involved the collection of offshore sediment samples along 14 different transects. The University of Wollongong’s School of Earth and Environmental Sciences (SEES) boat was used and field work was carried out with the help of Colin Murray-Wallace and Errol McLean. Weather conditions were ideal for working offshore with fine conditions, very light southerly breeze and calm seas.

Two individual sediment samples were taken along each transect, one close to the shore line and the other out perpendicular from the shore approximately 200 m. The idea of this sampling method was to gain an insight into differences there may be between sediments close to the shore and sediments further offshore, and also to determine the bathymetry of the study area. Each transect started approximately half way between each of the groynes along Lady Robinsons Beach. Sediments were collected using a hand-held sediment scraper designed by Errol McLean that was dropped over the edge of the boat and dragged for a short distance along the sea floor. The sediment was collected in the sample, brought back up into the boat and stored in sample bags for later analysis.

![Sediment Sampler](image)

Figure 3-1: The sediment sampler used during offshore field work at Lady Robinsons Beach.

A Seducer Pro echo sounder on board the boat was used to record water depths and coordinates during the sampling. This data was recorded between the start and finish point of each transect. The aim of this was to allow each transect’s water depth profile and subsequent bathymetry to be determined. The depth of each profile was obtained and displayed graphically using Microsoft Excel 2007.
More field work was carried out at Lady Robinsons Beach on Thursday June 30th between 8:30am and 11:30am. The tide during this study time ranged from 1.29 m (high) at 7:26am to 0.54 m (low) at 12:58pm. The field work on this day involved the collection of onshore sediment samples. Two sediment samples were taken from the water line approximately 5 m either side of the groynes (one to the north the other to the south). The sediment samples were collected in sample bags and stored for analysis. Detailed sample collection around two of the groynes, G1 and G8, was also undertaken. This involved getting into the water and diving to the bottom to collect samples around the groynes. The first sample was taken halfway out along the north side of each groyne, the second from approximately 5 m off the eastern end of the groynes and the third halfway along the groynes on the southern side (see Figure 3-2).

Follow up onshore sediment sampling was undertaken on September 27th between 3:15pm and 3:45pm. Low tide was at 1:47pm. Four onshore sediment samples were taken from the large sediment accumulation site on the southern point of Lady Robinsons Beach.

3.2. Sediment Analysis

In total 59 sediment samples were collected during the two days of fieldwork at Lady Robinsons Beach. Particle size analysis was undertaken on these 59 of these samples on Tuesday July 12th using the Malvern Mastersizer 2000 Particle Size Analyser that belongs to the University of Wollongong.

This particle size analysis gave mean, mode and median grain sizes, as well as the standard deviation (sorting) of the sediment samples taken from Lady Robinsons Beach. It also categorised the sediment, according to the Udden-Wentworth scheme, into sand, silt or clay. The results of this
analysis were recorded and graphical outputs created using Microsoft excel 2007. The aim of this sediment analysis was to give an insight into the nearshore sediments existing around Lady Robinsons Beach.

3.3. Statistical Analysis
The computer software program JMP version 7.0.2 was used to undertake some simple statistical tests on the results of the particle size analysis. Several t-tests were computed using JMP. Results from these tests were used to determine the statistical significance of the results of the particle size analysis.

3.4. Change Detection Analysis
Historical aerial photographs were obtained from the Rockdale City Council and used to undertake a change detection analysis on Lady Robinsons Beach. The aerial photographs were recorded in 1943 (in the northern regions of the beach), 1977, 1989, 2000, 2003, 2005, 2007, 2009 and 2011. The photographs display the entire length of Lady Robinsons Beach and therefore were ideal in observing long-term changes in the morphology of Lady Robinsons Beach both before and after the construction of the groyne fields.

The change in beach morphology was determined by observing the change in foreshore of a certain area in each of the historic photographs. The length of structures, such as the groynes, was used as reference points to estimate the length the beach had eroded or accreted. By doing this the changing nature of the morphology of Lady Robinsons Beach could be recorded and conclusions drawn both about historical sediment patterns in the bay and also the effect of the groynes constructed along the beach.

3.5. Map Outputs
The GIS computer program ArcGIS 10.0 was used to create map outputs for certain aspects of the project. Aerial imagery was obtained from nearmap.com through the spatial analysis laboratory (SAL) at the University of Wollongong and was used in compliance with the software program ArcGIS 10.0.

ArcGIS 10.0 and nearmap.com where used to give outputs displaying the study area, the onshore sampling locations, the offshore profile lines, and the offshore sampling locations. Information from the sediment particle size analysis as well as the data regarding the bathymetry of the bay was recorded in ArcGIS 10.0 allowing this data to be observed for specific points.
4. Results

4.1. Change Detection Analysis

Historical aerial photographs were obtained from the Rockdale City Council and used to observe and describe the geomorphological changes that have occurred on Lady Robinsons Beach. The aerial photographs displayed below focus on the areas of the beach that have undergone noticeable change as well as some closer points of interest. In the Northern regions of the beach historical photographs date back to 1943 whereas in the Southern regions (south of Dolls Point) the first recorded photograph is from 1977. The amount of erosion/accretion was estimated using the length of the groynes as a reference. The groynes are approximately 100 m long. By measuring the amount of erosion/accretion displayed in the aerial photographs an approximate value for the width of erosion/accretion was determined.

It must be remembered that some of the changes between photographs may be as a result of varying tides between the images. The tides in Botany Bay range from approximately 1.7 m at high tide to 0.15 m at low tide (Australian Government Bureau of Meteorology 2011). While this is a relatively small tidal range it must be considered when analysing the results of the change detection analysis.
4.1.1. Southern Groyne Field
Figure 4-1: Historical aerial photography of the first five groynes in the southern groyne field of Lady Robinsons Beach (source: Rockdale City Council). These groynes were constructed in 1997. Note: 1943 image incomplete as Rockdale City Council’s records only extend part of the way down the beach. Scale = 1:20,000.

This set of aerial photographs shows the Southern section of Lady Robinsons Beach to Dolls Point. The groynes present are the Northern five groynes from the initial groyne field built at Lady Robinsons Beach in 1997. Significant erosion patterns can be observed prior to groyne construction particularly from 1977-1989. In these two photographs a large portion (approximately 15-20 m) of sediment had been eroded from the beach to the North (red oval). It can also be observed in the photographs that there was a distinct lack of beach in the Southern portion from at the latest 1977 until 2000 (green oval).

Post groyne construction, there has been an obvious widening of the beach with exposed sand clearly visible. This accretion equals up to 80 m on the upstream side of some of the groynes. However, there appears to be some erosion of the beach front still occurring. These areas are highlighted by the yellow ovals from 2007-2011. This erosion is approximately 5 m. As suggested in
the literature (Clark 1996; Mangor 2004) there is an observable build-up of sediment on the upstream (northern) side of the groynes.

The shallow sandbar that can be observed in these photographs (particularly in 2007) is called Taylor Bar (Connell Wagner Pty Ltd 1999). A layer of sand taken from here was used in the nourishment of the northern groyne field (Connell Wagner Pty Ltd 1999).

4.1.2. Northern Groyne Field
Figure 4-2: Historical aerial photography of the northern groyne field at Lady Robinsons Beach built in 2003 (source: Rockdale City Council). Images from 1943-2011. Red arrow indicates the null point of longshore sediment transport. The majority of this area appears to have been stabilised by the construction of the groynes. Scale = 1:25,000.

This set of photographs displays the northern groyne field (five groynes), constructed in 2005. They cover the area from Solander Street to Florence Street. The red arrow on the photographs indicates the null point of longshore sediment transport. North of the arrow sediment is transported...
northward whereas south of the arrow sediment is transported southward. This can be confirmed by observing the build-up of sediment on the side of the groynes in the 2007 photograph. This null point is controlled by the angle of the waves approaching the shoreline. North of the null point the sediment is built-up on the Southern side of the groynes (yellow ovals). South of the null point the sediment is built-up on the North side of the groynes (purple ovals).

There is obvious erosion of the entire beach front from 1943-2005. The foreshore in the 1943 photograph appears relatively wide and straight which suggests a stable beach. From then on there is significant erosion of the beach resulting in basically no beach at all in 2003. From 2000-2003 it appears that the shore has retreated all the way to the seawall (red ovals).

Similar to the southern groyne field photographs the construction of the groynes coincides with a significant widening of the beach front (up to 60 m in some places). However, there are still points on the beach where small scale erosion still appears to be taking place (green ovals). A ground level view of this area is displayed in Figure 4-3.

Figure 4-3: Photographs showing a point of erosion between G4 and G5 (Source: Frost 2011). Very little beach remains here and on a high tide water reaches the rubble seawall. This area has been eroding since 2005.
4.1.3. North Lady Robinsons Beach
This set of photographs display the northern end of Lady Robinsons Beach, north of where the second groyne field was constructed. As with the previous photographs, in 1943 the beach appeared to be relatively wide. Sections of this area have encountered erosional processes over time. The region marked by the red ovals has been significantly eroded since 1977. This area can be observed from a ground level perspective in Figure 4-5. Some sections of the beach have a very narrow exposed beach with a wider section covered by shallow water (green ovals). The photographs don’t show any areas of significant sediment accumulation.

This set of photographs also shows the significant change to the physical appearance of Botany Bay that the construction of the original North-South Runway had. The runway juts out in front of the northern most end of Lady Robinsons Beach and shelters it from any significant wave action.
Figure 4-5: Photographs from the area to the north of G1 (Source: Frost 2011). These photographs show the severity of the erosion that has occurred in this region. The beach is cut back right to the vegetated dune region. It is possible that some of this erosion is due to recent storm activity.
4.1.4. Southern Rubble Seawall/Dolls Point
Figure 4-6: Historical aerial photography of the southern rockwall, G9 (north), and G10 (south) at Dolls Point, Lady Robinsons Beach (source: Rockdale City Council). After an initial stage of accretion after the construction of the groynes, this area is now steadily eroding. Scale = 1:10,000.

Significant changes in beach morphology can be observed in the above set of photographs. These photographs are from the Southern portion of Lady Robinsons Beach to Dolls Point and feature the ninth and tenth groynes.

The 1977 photograph shows that there was little/no beach at the time and that the water reached the rubble seawall that had been constructed. There is however sand present further south at Dolls Point. There is slightly more sand in the 1989 photograph. Post groyne construction however there is a significant increase in the amount of sediment present. From 2000-2005 the beach has been widened by up to 80 m.

From 2005-2011, however, it appears that large scale erosion of the beach is still taking place. The sand in front of the seawall is eroded back until it is once again exposed to the water in 2011 (red ovals). A ground level view of this is displayed in Figure 4-7. Once again considering the length of the groynes is approximately 100 m we can conclude that adjacent to G10 there has been about 70 m of erosion.

The amount of sediment trapped by G10 also greatly varies from 2000-2011. From 2000-2005 the groyne appears to be trapping sediment effectively and in 2007 the sand actually passes right around the eastern point of the groyne (yellow oval). The 2007 photograph is also the only photograph in the set in which breaking waves can be observed offshore. From 2007-2011 the amount of sand trapped by G10 greatly reduces to the current 2011 morphology (see Figure 4-8).
Figure 4-7: Photographs showing an aerial and ground view of the rubble rockwall between G9 and G10 (source: Frost 2011). No beach exists here.

Figure 4-8: Photographs showing the area to the south of G10. Very little beach now exists here with water reaching the seawall at high tide (source: Frost 2011).
4.1.5. Southern Point of Lady Robinsons Beach/Dolls Point
The Southern point of Lady Robinsons Beach is another place that has/is going under morphological changes. From 1977-1989 there is a build-up of sand in the South-Western corner of the photograph. Sediment is lost in the areas indicated by the red ovals. During this time a jetty was also constructed (arrow).

From 1989-2011 there is a steady and significant increase in sediment in this area. The groyne running parallel to the jetty is now almost completely covered by sand and the jetty barely reaches the water (see 2011 photograph arrows). There is also a large increase in the sediment located in the South-Western corner of the photograph (green circle). It is evident when analysing this set of aerial photographs that there has been a significant build-up of sediment in the area since 1989 which has resulted in the widening of the beach and the burial of the groyne.

4.1.6. Summary
Since 1943, aerial photographs of Lady Robinsons Beach have been recorded by the Rockdale City Council. Upon review of these photographs it is evident that sediment movement on Lady Robinsons Beach has been dynamic and is still ongoing. Table 4-1 summarises the changes that have occurred in certain areas as eroding, accreting or in a period of stability. The results of this change detection will be discussed in further detail in section 5.1.
Table 4.1: The state of the beachfront along varying regions of Lady Robinsons Beach. The first recorded photographs for each particular area were used as a reference for the more recent photographs.

<table>
<thead>
<tr>
<th>Year</th>
<th>Southern Groyne Field</th>
<th>Northern Groyne Field</th>
<th>Northern LRB</th>
<th>Dolls Point</th>
<th>Southern LRB</th>
</tr>
</thead>
<tbody>
<tr>
<td>1943</td>
<td>Reference</td>
<td>Reference</td>
<td>Reference</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>1977</td>
<td>Erosion</td>
<td>Erosion</td>
<td>Accretion</td>
<td>Reference</td>
<td>Reference</td>
</tr>
<tr>
<td>1989</td>
<td>Erosion</td>
<td>Erosion</td>
<td>Erosion</td>
<td>Accretion</td>
<td>Erosion</td>
</tr>
<tr>
<td>2000</td>
<td>Accretion</td>
<td>Erosion</td>
<td>Stable</td>
<td>Accretion</td>
<td>Accretion</td>
</tr>
<tr>
<td>2003</td>
<td>Accretion</td>
<td>Erosion</td>
<td>Stable</td>
<td>Stable</td>
<td>Accretion</td>
</tr>
<tr>
<td>2005</td>
<td>Stable</td>
<td>Accretion</td>
<td>Stable</td>
<td>Stable</td>
<td>Accretion</td>
</tr>
<tr>
<td>2007</td>
<td>Erosion</td>
<td>Accretion</td>
<td>Erosion</td>
<td>Erosion</td>
<td>Accretion</td>
</tr>
<tr>
<td>2009</td>
<td>Erosion</td>
<td>Stable</td>
<td>Erosion</td>
<td>Erosion</td>
<td>Accretion</td>
</tr>
<tr>
<td>2011</td>
<td>Erosion</td>
<td>Stable</td>
<td>Erosion</td>
<td>Erosion</td>
<td>Accretion</td>
</tr>
</tbody>
</table>

4.2. Offshore Profiles

4.2.1. Bathymetry

In total 14 offshore profiles were recorded and their location plotted in Figure 5-5. From this profiling the nearshore bathymetric changes were able to be determined. The depth data recorded during profiling was recorded and then plotted as graphs using Microsoft Excel 2007.
4.2.2. Offshore Sediment Analysis

Figure 4-10: The mean particle size of the offshore sediment samples. Measured in phi (Φ) units.

Figure 4-11: The composition of the offshore sediment samples.
4.2.2.1. Sorting & Skewness

Figure 4-12: Offshore sediment samples taken from Lady Robinsons Beach sorting vs skewness.

4.3. Onshore Sampling

4.3.1. Sediment Analysis

Figure 4-13: The mean particle size of the onshore sediment samples taken from Lady Robinsons Beach. Measured in phi (\(\Phi\)) units.
4.3.1.1. **G1 Detailed Sampling**

Figure 4-14: The composition of the onshore sediment samples taken from Lady Robinsons Beach.

Figure 4-15: The mean particle size of the samples taken around G1. Measured in phi (Φ) units.
4.3.1.2. **G8 Detailed Sampling**

![G8: Mean Particle Size Phi (Φ)](image)

Figure 4-16: The mean particle size of the samples taken around G8. Measured in phi (Φ) units.

4.3.1.3. **South Point Detailed Sampling**

![South Point: Mean Particle Size Phi (Φ)](image)

Figure 4-17: The mean particle size of the samples taken on the Southern Point of Lady Robinsons Beach. Measured in phi (Φ) units.
4.3.1.4. Sorting & Skewness

Figure 4-18: Onshore sediment samples taken from Lady Robinsons Beach sorting vs skewness.

5. Discussion

5.1. Change Detection Analysis

Change detection analysis was undertaken on the historical aerial photographs (1943, 1977, 1989, 2000, 2003, 2005, 2007, 2009 and 2011) of Lady Robinsons Beach. These photographs were provided by the Rockdale City Council. By comparing photographs from different years, changes in the morphology of the beach could be determined. Also using the length of the groynes (approximately 100 m) as a reference, approximate values for beach erosion/accretion could be determined. This allowed for the erosional patterns of Lady Robinsons Beach to be determined and also allowed for comment on the effectiveness of the groynes in stabilising the beach and preventing erosion.

The results of the change detection analysis suggested that sediment transport on the beach is still dynamic and erosion/accretion is still taking place in many areas, some more substantial than others. The historical aerial photographs also give insight into the morphology of the beach prior to the construction of the groynes. This allows conclusions to be drawn on the effects of human developments in the Botany Bay region.
5.1.1. Pre-groyne Geomorphology of Lady Robinsons Beach

The aerial photographs from 1943 generally show a relatively wide, straight beachfront suggesting that at the time Lady Robinsons Beach was relatively stable (see Figure 5-1). Post 1943, however, the width of the beach declines significantly and in places no permanent beach exists (see Figure 5-1). Possible tidal variations must be considered when observing these changes in beach width. While a high tide of approximately 1.6 m (common for Botany Bay) would reduce the beach width it is unlikely that it would be the cause change to the extent visible in these photographs. Therefore, for this study, tidal variations affecting Lady Robinsons Beach were considered, however, for areas showing large scale change the affect of the tide was considered unimportant. To determine the reasons for the large scale erosion/accretion of the beach the human history of Botany Bay must be considered.

As mentioned previously, the first major human-induced physical changes to Botany Bay began in the late 1930’s and early 1940’s with the diversion of the Cooks River to allow for the construction of
new runways in the developing Sydney Airport (Sydney Airport 2010). The path of the river was altered and an artificial river mouth leading into Botany Bay was created. This artificial river mouth is to the South West of the original, natural entrance of the river into the bay (see Figure 1-12). More significantly, however, were the dredging events undertaken for the construction of the parallel runways of the Sydney Airport, and Port Botany. It was reported by Dames & Moore Pty Ltd (1995) that only 53% of the 6,000 m³ of erosion predicted to occur annually on Lady Robinsons Beach, would have occurred naturally. The remaining 47% was a result of the human activities in the bay such as dredging, and land reclamation for the construction of the runway and Port Botany. These were the results of a coastal modelling experiment carried out after to the construction of the second parallel runway in the 1990’s. It was undertaken as part of an experiment to determine the impacts the construction of the runway was having on the surrounding environment.

The retreat of the shoreline since 1943 suggests that there is a correlation with the human developments in the bay as these started approximately at the same time. Figure 4-2 shows the large scale erosion that occurred from 1977 until 2003 when the groynes were constructed. The original north-south runway reached its current length in 1972 which coincides with the increased erosion of Lady Robinsons Beach. The numerous dredging and land reclamation events that have taken place inside Botany Bay have obviously had an effect on the wave regime of the bay which has led to longshore sediment transport and erosion of Lady Robinsons Beach.

5.1.2. Post Groyne Geomorphology of Lady Robinsons Beach

In total there are 11 rock rubble groynes built on Lady Robinsons Beach which were designed to control the erosion of the beach front by trapping portions of the longshore sediment transport. The groynes are constructed using basalt armoury and are approximately 100 m long. The first of these groyne fields was finished in 1997 and were placed on the southern portion of the beach south of Florence Street to Dolls Point. This involved the construction of six groynes. The second groyne field was finished in 2005 and consists of five groynes built between Solander Street and Florence Street. As previously mentioned a null point of the longshore sediment transport exists approximately adjacent to Pasadena Street (see Figure 2-4). There are three groynes to the north of this point which are designed to catch the northbound sediment. The remaining eight groynes are situated south of the null point and are trapping southbound sediment.

The historical aerial photographs show that despite the construction of these groynes there is still a great deal of erosion and accretion of sediment occurring in localised areas of Lady Robinsons Beach. While certain areas of the beach appear to have been stabilised as a result of the construction of the groynes and the sand nourishment of the beach, other sections appear to still be significantly

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effected by erosion and accretion. The following are areas where there appears to be ongoing erosion/accretion occurring.

5.1.2.1. Southern Rubble Seawall & Dolls Point

As shown in Figure 4-6 this beach area is still undergoing significant erosional processes. The 1977 photograph shows no beach present and the water reaching the constructed rubble seawall. After the construction of the first groyne field in 1997, the photographs show a much wider beach particularly to the south. In 2007 there has been approximately 100 m of accretion of the beach on the north side of G10. This suggests that, at least temporarily, that the groynes were effective in stabilising and widening the beach. However, from approximately 2003 onwards, the beach front adjacent to the seawall has been greatly reduced, and the seawall is now once again exposed directly to the water. This is equal to approximately 15 m of erosion. Even the large build-up of sediment that occurred on the upstream (northern) edge of G10 has been greatly reduced. This erosion is approximately 70m. On high tide water reaches the seawall in the areas just to the north and south of G10 (see Figure 4-8).

A possible explanation for this is the construction of the northern groyne field. This may have resulted in too much sediment being trapped further north and not reaching this far south. This, however, is unlikely because there is large scale sediment accumulation occurring on the southern point of the beach (see Figure 4-9 and paragraph below). Therefore it must be concluded that, for this area at least, the construction of the groynes has not been effective in stopping the longshore sediment transport and subsequent beach erosion.

Another possible explanation for the erosion in this area is effects from the deepening of Taylor Bar to provide sand for nourishment of the northern groyne field. This scraping of sediment from Taylor Bar was estimated to cause a possible 2.5m erosion of the beach in the adjacent area. The historical aerial photography shows definite erosion in the area post-2005 which suggests there may be a correlation between the scraping of Taylor Bar and the erosion of this area of Lady Robinsons Beach. It was also stated by Connell Wagner Pty Ltd (1999) in the EIS for the northern groyne field that a 1 in 20 year storm event would lead to 0.6m of sand being scoured away from the seawall in this area. Storm records are hard to follow however it is possible that a large storm event triggered the erosion in the area. However, the erosion in this area has been large scale (up to 50m at some points) and the erosion has continued suggesting that these processes are ongoing and probably not controlled by storms. The failure for the area to recover suggests that the groynes to the north of this point are ineffective at trapping southward moving sediment and stabilising the beach in this area.
5.1.2.2. Southern Point of Lady Robinsons Beach

This portion of Lady Robinsons Beach, since 1989, has been significantly widened due to the accretion of large amounts of sand (see Figure 4-9). This phenomenon appears to be contrary to what would be expected. Chapman *et al* (1982); Komar (1998); Charlier & Meyer (1998) & Mangor (2004) all claim that the downstream regions of a groyne field are starved of sediment. Although this section of the beach is still part of the groyne field it would be expected, given that it is on the Southern edge of the field, that there would be less sediment available from the southbound longshore sediment transport. This is obviously not the case as there is more sediment accumulation here than on any other portion of Lady Robinsons Beach (~130 m). The most Southern rubble groyne, G11, is almost completely covered by sediment with only portions of rocks exposed (see Figure 5-2). This highlights the massive amount of sand accumulation that has occurred along this portion of the beach and also suggests that the groynes are not completely effective at controlling the longshore sediment transport issue on Lady Robinsons Beach.

Figure 5-2: The most Southern rock-rubble groyne on Lady Robinsons Beach, G11 (source: Frost 2011). The groyne is almost completely covered by sand and the beach extends way beyond the tip of the groyne. This photograph was taken 26/8/2011 at approximately 11:30am. For reference purposes the width of the exposed groyne is between 4 and 3 m.

Sediment samples both onshore and offshore of this region were collected and analysed to determine composition and grain size. The locations of these onshore samples are displayed in Figure 5-3. Like almost all of the onshore samples taken, the sediment in the region is classified as medium sand. The particle-size distribution histogram for the sediment samples taken adjacent to

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G11 are displayed in Figure 5-4. The sediment in this region varies from most other onshore areas of Lady Robinsons Beach and will be discussed in detail in section 5.2.3.4.

Figure 5-3: Aerial photograph showing the locations of the onshore sediment samples taken from the Southern Point of Lady Robinsons Beach (source: nearmap.com 2011).

Figure 5-4: The particle-size distribution histogram for sediment sample LR11/31 (top) & LR11/32 (bottom). These samples were collected from the area around G11. This area has experienced massive accretion since 1989.
This southern portion of the beach may be acted upon during times of high flow by the Georges River, which enters the bay to the south-west of this point. It is unlikely, however, that these forces are substantial in shaping the morphology of the beach in this region.

5.1.2.3. **Northern Groyne Field**

Despite there being sections of Lady Robinsons Beach where erosion is still an obvious problem, there are also sections where the implementation of groynes has appeared to stabilise the beach, at least temporarily. Figure 4-2 shows the abrupt change in beach front from 2003 when there were no groynes to 2005 when the groynes had been constructed. This widening was up to 50 m in some places. From 2005 onwards the beachfront appears to remain relatively stable in most places in this area. This suggests that the Northern groyne field has been successful in widening and stabilising the beach in a localised area.

There is, however, one particular area that has been eroded since the construction of the groynes. It is a small, localised area situated between G4 and G5. There is a small rubble seawall, similar to the one at Dolls Point, at this point of erosion. Figure 4-3 shows how currently (at high tide) there is very little beach here. The beach in this area has narrowed by about 10 m since 2005 suggesting that while the surrounding groynes were relatively successful in widening and stabilising the beach, in this particular area they have not been.

5.1.2.4. **North Lady Robinsons Beach**

Some regions north of this groyne field appear to still be affected by erosion or possible sediment starvation. The area directly to the north of G1 appears to have been narrowed since the construction of the groynes (see Figure 4-4). This is in accordance with Chapman et al (1982); Komar (1998); Charlier & Meyer (1998); Mangor (2004), who stated that the construction of groynes starved the adjacent down-drift areas of sediment often leading to localised erosion. However the sharp sand banks and extremely narrow beach (see Figure 4-5) suggest that this region is not only starved of sediment but is also being severely eroded. The historical aerial photographs show that since the construction of the G1 in 2005 this section of the beach has narrowed by approximately 10 m. The construction of the northern groyne field may have widened the beach in some areas but it is clear that this particular region of the beach is still being eroded and is in need of a solution to the erosion problem.

5.1.3. **The Erosion of Lady Robinsons Beach & Effectiveness of the Groynes**

The reasons behind these erosional processes lie within the human history of the bay. Significant changes to the bathymetry as a result of dredging and land reclamation (see Figure 1-14) have clearly influenced the wave regime reaching Lady Robinsons Beach. It is the refraction of the

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incoming waves that has led to the longshore sediment transport (Jones 1981; Fitzgerald 1998; Connell Wagner Pty Ltd 1999; Sydney Ports Corporation 2002; Aijaz & Treloar 2003). The photographs from the year 1943, which dates back to around the time that major human changes started taking place in the bay, show a relatively wide beach. This suggests that before human development began in the bay Lady Robinsons Beach was a stable foreshore. Significant dredging and land reclamation events in the bay have severely altered the natural bathymetry of the bay. It is these alterations that have led to the refracted wave patterns that reach Lady Robinsons Beach creating longshore currents and subsequent longshore sediment transport.

The historical aerial photographs clearly shows that from 1943 until the construction of the groyne fields, in 1997 and 2005, Lady Robinsons Beach underwent severe erosion, completely eliminating any foreshore in several places. The construction of the groyne fields along the beach obviously resulted in significant widening of the beach, however, it appears that the problem has not been completely resolved. The massive accumulation of sand on the Southern reaches of Lady Robinsons Beach suggests that there is still significant longshore sediment transport taking place. There are 10 groynes constructed to the north of this point of which seven are south of the null point of sediment transport. According to the literature the areas downstream of a groyne field will become starved of sediment due to it being trapped upstream. This is clearly not the case at Lady Robinsons Beach.

There is obvious localised erosion also occurring at several areas of the beach. The areas around the Southern rubble seawall and G10 (see Figure 4-6), around the small rubble seawall between G4 and G5 (see Figure 4-3), and directly north of G1 (see Figure 4-5) also suggests that sediment transport is still ongoing.

The construction of the groyne fields was never going to stop the erosional processes on Lady Robinsons Beach. They are used to help widen and stabilise particular areas of beachfront by trapping longshore sediment transport, not to halt the processes leading to the littoral drift (Chapman et al 1982; Viles & Spencer 1995; Clark 1996; Charlier & Meyer 1998; Woodroffe 2002; Masselink & Hughes 2003). It does appear that in certain areas the groynes have been successful in doing this. The beachfront between G1 and G4 appears to be remaining relatively stable as does the area between G5 and G9. However as Valiela (2006) suggested is normally the case, the construction of these groynes also seems to have had some negative impacts on the areas surrounding them. Most notably is the area to the north of G1 which as discussed is severely eroded. This is probably due in part to starvation of sediment because of G1 and also due to the ongoing erosional processes along Lady Robinsons Beach.
It is clear, upon observation of the historical aerial photography, that the groynes constructed on Lady Robinsons Beach have led to localised widening of the beachfront but in other areas have not been effective in stabilising the beach. They have also led to significant sediment starvation to the north of the groynes leading to severe erosion in this region. At some stage remedial action is likely going to be needed in this area in order to protect this stretch of beachfront and dune region.

5.2. Field Work and Sediment Analysis

5.2.1. Offshore Profiling-Bathymetry
The profiles surveyed along Lady Robinsons Beach range in distance from approximately 110 m to 360 m. The locations of these profiles are displayed in Figure 5-5. The results from the depth soundings of the profiles provide good insight into the nearshore bathymetry of Lady Robinsons Beach, emphasising the changes that occur in the beach profile in specific areas.

In the north the beach drops away rapidly over distances of approximately 20 m reaching depths of between 3.5-4.0 m (see profiles 1-3). After this rapid drop-off the depth of the beach remains relatively level over the rest of the profile (up to approximately 180 m).

Profiles 4-7 differ from profiles 1-3 significantly in gradient. The drop-off in this area of the beach is not as sudden with profiles taking between 60 m and 90 m to reach significant depth. The depth of these profiles is relatively similar to the northern end of the beach. Depths range from approximately 3.5-5.0 m over distances of around 200 m. Profile 5 is slightly deeper than the others reaching a maximum depth of 4.82 m.

Profile 8 differs significantly from the profiles either side of it. It has a much lower gradient and is shallower compared to profiles 7 and 9. This profile was also taken over a much longer distance. It gradually deepens over a distance of around 250 m reaching a maximum depth of only 3.5 m. Profile 8 was taken perpendicular to the beach area displayed in Figure 5-6 and a close up of the profile is shown. This is an area that has undergone significant localised erosion to the point where very little beach exists. It is possible that the lack of a developed beach front or the rubble seawall constructed there may affect the offshore profile in this region. According to Woodroffe (2002) seawalls reflect incoming wave energy. With no beach front for wave energy to be dissipated upon the incoming waves in this region are often reflected back out to sea. This would likely result in the shallower conditions and smaller gradient.
Figure 5-5: An ArcGIS 10.0 output displaying the locations of the 14 profiles taken along Lady Robinsons Beach (source: nearmap.com 2011).
The next two profiles (9 and 10) are similar both in gradient and depth. They both deepen relatively quickly, reaching depths of around 4.5 m after approximately 100 m after which they level out.

Farther south of profile 10 the bathymetry of the bay changes dramatically. It becomes much shallower and there is little increase in depths along the profiles. Profile 11 deepens by around 1 m over the first 50 m of the profile but then remains relatively flat for the remaining 300 m of the profile. Profile 11 also becomes shallower by approximately 60 cm between 240-275 m along the transect. This area of the bay has been named Taylor Bar and it was one of the sites that sediment was taken from for the nourishment of the northern groyne field (Connell Wagner Pty Ltd 1999). As can be seen in the computerised profile lines, profile 11 is not straight. After approximately 200 m it swings to the north before turning back to the east again. This may be the cause for the slight rise in the bathymetry. Profile 12 is very similar to 11 but it is only measured over a distance of around 175 m and only reaches a depth of approximately 2.5 m.

Profile 13 is even shallower than 11 and 12. Unlike the two profiles before it, it hardly deepens at all along its 200 m length. Its starting depth is around 1.6 m and it finishes just over 2 m deep. Similarly to profile 8, profile 13 was recorded in front of the seawall depicted in Figure 5-7. Reflected wave energy may cause this area to remain relatively shallow and not deepen dramatically offshore.
Profile 14 appears similar to the northern end of Lady Robinsons Beach then profiles 11-13. It deepens dramatically over a short distance (approximately 70 m). It is located further south and around Dolls Point from profile 13 suggesting that there is a significant difference in bathymetry between these two areas.

There is an obvious change in gradient from the north of the beach with depth becoming shallower around the groynes. The beach profile then changes again dramatically on the southern point of the beach. Thus the far-northern and far-southern regions of Lady Robinsons Beach are similar in terms of bathymetry and the middle portion differs. This change in bathymetry can be observed in the graph displayed in appendix E.

5.2.1.1. Summary

A summary of the nearshore bathymetry is outline in Table 5-1.

Table 5-1: A summary of the nearshore bathymetry of Lady Robinsons Beach as tested during field work.

<table>
<thead>
<tr>
<th>Profile No.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Profiles 1-3</td>
<td>Steep gradient before levelling out after approximately 20 m. Max depth=4 m</td>
</tr>
<tr>
<td>Profiles 4-7</td>
<td>Shallower gradient then profiles 1-3. Levels out after approximately 90 m. Max depth=5 m</td>
</tr>
<tr>
<td>Profile 8</td>
<td>Very shallow gradient. Deepens along the profile. Max depth=3.5 m</td>
</tr>
<tr>
<td>Profiles 9 and 10</td>
<td>Similar gradient to profiles 4-7. Levels out after approximately 110 m. Max depth=4.9 m</td>
</tr>
<tr>
<td>Profiles 11-13</td>
<td>Little to no gradient i.e. bathymetry is flat. Max depth=3 m.</td>
</tr>
<tr>
<td>Profile 14</td>
<td>Similar gradient to profiles 1-3. Levels out after approximately 60 m. Max depth=5 m</td>
</tr>
</tbody>
</table>
Nearshore profiling of Lady Robinsons Beach revealed that there is several significant changes within the local bathymetry. In particular there is a region of the nearshore that is relatively flat and shallow (profiles 11-13) when compared with the rest of the beach. The shallower nature of this area of the beach is emphasised in Figure 4-6 where breaking waves can clearly be seen in the 2007 aerial photograph. The shallower nature of the beach in this region allows waves to break further offshore dissipating energy over a wider distance. It is this wider surf zone that ensures the area remains shallower and flater than the other regions of the beach. Other sections of the beach, such as the north (profiles 1-3), are much steeper suggesting a reflective or intermediate beach where waves break much closer to the shore (Komar 1998).

The varying bathymetry in the nearshore region of Lady Robinsons Beach suggests the wave regime along the beach varies significantly. This change in wave regime was caused as a side effect of the numerous dredging and land reclamation events that took place to allow the construction of the parallel runways and Port Botany. It is these changes in wave regimes that have led to the refraction of incoming waves and subsequent longshore sediment transport effecting Lady Robinsons Beach (Jones 1981; Chapman et al 1982; Trindade et al 1993; Aijaz & Treloar 2003).

5.2.2. Offshore Sediments

Particle-size analysis undertaken on the offshore sediment samples taken during profiling revealed that the majority of the sediment in the nearshore region of Lady Robinsons Beach is classified as medium sand (=2-1 Φ). Full results from the sediment particle size analysis are displayed in appendix A. These samples were taken from the start (shoreward side) and end (seaward side) of each of the profiles (see Figure 5-8).
Figure 5-8: An ArcGIS 10.0 output displaying the approximate locations of the offshore sediment samples (Source: nearmap.com 2011).
5.2.2.1. Sediment Sorting & Skewness

Most of the sediment samples collected from the offshore region of Lady Robinsons Beach showed good sorting and skewness close to 0 (see Figure 4-12 & appendix A). Good sorting of sediments on beaches is common due to their continued re-working by wave action (Blatt et al 1980; Komar 1998; Masselink & Hughes 2003). The energy expelled by the breaking waves bring finer particles into suspension and carries them offshore or cross-shore leaving behind sediments of relatively similar sizes. This continued re-working results in well sorted sediments. The skewness of a sediment sample is determined by plotting the particle size of sediments into a histogram. A histogram that is near symmetrical suggests that the particle sizes in a sample are concentrated around a similar value. Therefore is it common for a sediment sample that is well sorted to also have low skewness.

The particle size histograms for the offshore sediment samples are displayed in appendix C.

There are, however, some localised areas of Lady Robinsons Beach that contained poorly sorted sediments. These five samples are LR/7, 13, 15, 17 & 31. All five of the poorly sorted sediment samples are from the end of their particular profiles (profiles 1, 5, 8, 9 & 10). Only one (profile 1) is made up of medium sand (1.67 Φ). The rest are classified as fine sand, very fine sand or silt (see appendix A). These samples are also all coarsely skewed (see appendix A) which, according to Masselink & Hughes (2003), suggests that while these areas are classified as fine sand, very fine sand, or silt, there is still an excess of coarse grains. As these samples were taken offshore it is likely that the lack of sorting and presence of finer grained sediments is a result of less wave energy then experienced elsewhere, most notably closer to shore. If wave energy was higher in these regions the finer grained sediments would become suspended and be transported either further offshore or along the coastline.

5.2.2.2. Particle Size

As shown in appendix A the sediments samples taken from the 14 profile lines along Lady Robinsons Beach vary in size from medium sand to silt. The majority of the samples, however, fall within the medium sand range (≈2-1 Φ). The sediments found in Botany Bay are marine sourced sediments due to their particle size and moderately-well sorted (Hann 1986; Albani & Rickwood 1998; Nichols 2009). As mentioned above, however, there are patches of finer grained sediments such as the silt found at the end of profile 10. Some sediment samples, most notably LR/7, LR/13, LR/15 and LR/17, contained traces of clay. This was also concluded by Albani & Rickwood (1998) who found areas of the unconsolidated sediments in Botany Bay contained silt and clay.

As expected many of the profiles showed finer sediments further out into the bay. As explained by Komar (1998); Woodroffe (2002); Masselink & Hughes (2003), sediment closer to the shoreline is
often coarser than sediments further offshore. This is due to the expulsion of wave energy on the shoreline resulting in the dispersion of the finer particles. This can be observed particularly along profiles 8-10 where there is a large reduction in mean particle size from the start the end of the profiles.

However, several of the profiles, particularly profiles 4 and 6, coarsen further offshore (see Figure 4-10). Profile 4 coarsens by around 0.37 $\Phi$ and profile 6 by approximately 0.26 $\Phi$. This is possibly due to the groynes trapping the littoral drift on the beach. Finer sediments are more likely to be transported along a beach by a longshore current as less energy is required to move these sediments (Woodroffe 2002). The groynes may be trapping these finer grained sediments as they are transported parallel to the shoreline. This could result in the slight coarsening of sediments offshore as under normal conditions these sediments would be removed from the area leaving coarser particles behind.

Statistical analysis was undertaken to determine whether there is a significant difference between the particle-size of the sediments from the beginning (western side) of the profiles compared to the samples from the end (eastern side) of the profiles. A t-test was used and the resultant p-value was 0.3842 (see appendix F for detailed results). Therefore, using a confidence interval of 95% we can conclude that there is no significant difference between the particle-size of the sediments at the start of the profiles compared to the sediments from the end of the profiles. Thus the variations in sediment particle size from near the shore to offshore can be discounted.

A similar statistical t-test was undertaken to determine whether there is a significant difference in the offshore sediment particle size from the northern half of the study area to the southern half (see appendix G for detailed results). Samples from profile 1 (LR/30 &31) to profile 7 (LR/10 &11) were grouped as northern beach. Samples from profile 8 (LR/12 &13) to profile 14 (LR/26 &27) were grouped as southern beach (see Figure 5-8 for locations). Profile 7 was chosen because it was recorded at the approximate location of the null point of sediment transport. The results from the t-test gave a p-value of 0.8191 meaning that, with a 95% confidence interval, it can be concluded that there is no significant difference in mean particle size of offshore sediments collected to the north of the beach to the south. These results suggest that the longshore sediment transport acting on the beach does not create any significant changes in sediment particle size in the nearshore region.

### 5.2.3. Onshore Sediment Analysis

The approximate locations of onshore sampling are depicted in Figure 5-9. In total 31 sediment samples were analysed from Lady Robinsons Beach shoreline between G1 and G11. One sample was taken to the north and south of each groyne at the waters edge. Several sediment samples were
taken from the regions surrounding G1 and G8. Four samples were also taken from the large accumulation of sediment around G11. Like the offshore samples particle-size analysis was carried out and the results are displayed in the results section of this report.

5.2.3.1. Sediment Sorting & Skewness
Unlike the offshore sediment samples there is very little variation in sorting and skewness of the onshore samples (see Figure 4-18). All are either moderately well sorted or well sorted (low standard deviation) and all but one (LR-II/4) are near symmetrical when plotted into a particle size histograms (see appendix D). Good sorting and near symmetrical skewness is expected as almost all of these samples were taken from within 5 m of the shoreline. Therefore they are acted upon by wave energy which causes constant reworking of sediment and results in well sorted sediment.

5.2.3.2. Particle Size
All the onshore sediment samples are categorised as medium sand and all but samples LR-II/4 and LRII/31 contained 100% sand (see appendix B). Most of the samples between the groynes show finer particle sizes towards the southern end. Another way of saying this is that finer sediments exist adjacent to the northern side of groynes and coarser sediments exist adjacent to the southern side of groynes. A t-test was undertaken to determine if this difference is significant (see appendix I for detailed results). The volume weighted means for the samples taken on the northern side of the groynes were grouped and compared statistically with the volume weighted means of the samples taken on the southern side of the groynes. The test gave an output p-value of 0.0022 and therefore, using a confidence interval of 95% it is concluded that there is a significant difference in sediment particle size from the north side of the groynes to the south side.

This pattern, however, is the same both north and south of the null point of sediment transport. This suggests that it may not be related to the patterns of longshore sediment transport at Lady Robinsons Beach. If it was controlled by the longshore sediment transport it would be expected that the pattern would be reversed on either side of the null point.

Another statistical test was undertaken to determine if there was a significant difference in sediment particle size from the northern half (LRII/3-LRII/15) to the southern half (LRII/16-LRII/30) of the study area. The samples taken from the south point of the beach were not included as they were not taken from the shoreline like the majority of the samples. The results of this t-test gave a p-value of 0.2742. Detailed results are given in appendix H. Therefore using a 95% confidence interval it was concluded that there is no significant difference in sediment particle size on the shoreline in the northern half of the groyne field to the southern half.

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5.2.3.3. **G1 & G8**
Detailed sediment collection was undertaken around G1 and G8 (see Figure 3-2). The graphical results from the particle size analysis are displayed in Figure 4-15 & Figure 4-16. There does not appear to be any clear pattern between the results. At G1 the coarsest sediments are found on the southern beach area whereas at G8 they are found off the eastern point of the groyne. In contrast to this the finest sediment at G1 is found off the eastern point of the groyne.

5.2.3.4. **South Point**
Detailed sampling was also undertaken on the large sediment accumulation on the southern end of Lady Robinsons Beach (see Figure 5-3 for locations). While all other onshore samples were taken from close to the shoreline (within 5 m) some of these samples (LRII/31, 32 & 34) were taken up to 50 m from the shore. These sediments have a much finer particle size than the sediments collected directly to the north. A t-test was undertaken to determine whether there is a significant difference in particle size of sediment samples LRII/26-30 compared to LRII/31-34 (see appendix J for detailed results). The results of the t-test showed a p-value of 0.0175 and therefore using a confidence interval of 95% we can conclude there is a significant difference.

The existence of finer sediments on the southern point of Lady Robinsons Beach is to be expected as they are not directly adjacent to the shoreline. Sediments on the shoreline are acted upon by waves, which bring finer particles into suspension and transport them away. This leaves coarser particles behind. Away from the shoreline there is obviously no wave energy acting. Sediment here is therefore able to dry out, at which point it is able to be reworked by wind energy (Nichols 2009). Typically sediments deposited by aeolian processes are well sorted (Nichols 2009). This is the case with the sediments collected from the southern point. The four samples collected also had a skewness factor of between 0.06 and 0 and are therefore classified as near symmetrical when plotted into a particle size histogram.

This region has obviously experienced large scale erosion and accumulation over the past four decades (from photographic records) and probably longer. Since the construction of the groynes accumulation has been so great here that the area has characteristics of a dune system, such as good sorting and finer sediments than surrounding areas (Nichols 2009). According to Pye & Tsoar (1990 p.163) aeolian deposited sand dunes are often created adjacent to obstacles such as boulders, escarpments, and hills. It is possible that this region of Lady Robinsons Beach is an aeolian sand dune deposit that was created due to the construction of G11. This suggests that the construction of the groynes in response to the longshore sediment transport occurring on the beach has led to significant changes in beach morphology.
Figure 5-9: An ArcGIS 10.0 output displaying the approximate locations of the onshore sediment samples (Source: nearmap.com 2011).
6. Conclusions & Recommendations

Sediment sample collection and analysis carried out both on offshore and onshore sediments showed that the majority of the sediment in the nearshore region of Lady Robinsons Beach is medium sand in particle size and composition. There was no significant change in sediment grain size or composition from the northern edge of the beach to the south or from the start to end of the offshore profiles. A significant difference in sediment particle size was found from the north of groynes to the south of groynes. This pattern, however, remains the same on either side of the null point and therefore it is unlikely it is caused by the longshore sediment transport in the region.

There is significant change in sediment particle size on the large scale accumulation of sediment on the southern point of Lady Robinsons Beach. The sediment here displays a significantly finer mean particle size than the areas to the north. It is likely that this deposit is mostly controlled by aeolian processes as the sediment here is not within the tidal range of the beach. This accumulation of sediment began after the construction of the first groyne field in 1997 and therefore it appears that these groynes, and in particular G11, have had a significant impact on the morphology of the beach in this region.

The bathymetry of the nearshore region of Lady Robinsons Beach varies along the beach. Differing wave patterns and energy levels along the beach are probably responsible for shaping the beach profile. Two of the shallower, flatter areas of the beach are also adjacent to regions on the beach that are undergoing erosion. This suggests a possible relationship between the bathymetry in these areas and the ongoing reduction of the beach. The lack of a significant beach front may affect the offshore bathymetry or vice versa.

It is clear that since the human developments in Botany Bay there has been significant sediment transport and subsequent erosion of Lady Robinsons Beach. Erosion was severe, particularly in the southern half of the beach and by the 1990’s there was very little beach left. Since the beginning of these erosional processes numerous actions have been taken to help protect the coastline, most notably the construction of the groynes along the beach.

It is evident, when examining the historical aerial photography taken of the region that these groynes have helped to significantly widen and stabilise Lady Robinsons Beach in many areas in the groyne field. However it is also clearly evident that erosion is still taking place along the beach in smaller, localised areas. This erosion is quite severe in several places, most notably to the north of G1 and around the rubble seawall to the south at Dolls Point. It is acknowledged in the literature that groyne fields are unable to stop the processes leading to erosion, however a well designed
groyne should help stabilise the shoreline in a localised area. This is clearly not the case for regions such as the rubble seawall at Dolls Point which has seen significant sediment loss in the last six years.

The starvation of the north-bound sediment is clearly evident in the area directly north of G1. Only a very narrow beach now exists here, with steep sand cliffs evidence of severe erosion. It is likely that remedial action is going to be needed in this area relatively soon to attempt to halt the erosion and minimise damage not only to the shore but also to the dune system in the area.

Therefore it must be concluded that while the groynes on Lady Robinsons Beach have been successful at stabilising and widening the beach in some areas, the continued erosion in and around the groyne field suggest that they are not entirely effective as a solution to the erosional processes acting upon Lady Robinsons Beach. Further study is recommended in the region to determine if the groynes can be improved to help the surrounding area. If not, alternative solutions to the erosional problems are possibly going to be required before the beach experiences irreparable damage.
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Appendices

A.

Appendix A: Detailed results from the offshore sediment samples particle size analysis

<table>
<thead>
<tr>
<th>Sample Name</th>
<th>Sand (%)</th>
<th>Silt (%)</th>
<th>Clay (%)</th>
<th>Clay 2um (%)</th>
<th>Mean (Φ)</th>
<th>Std</th>
<th>Sorting</th>
<th>Skew</th>
<th>Skew Description</th>
<th>Sediment Classification</th>
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<tr>
<td>LR/30</td>
<td>100</td>
<td>0</td>
<td>0</td>
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## Appendix B: Detailed results from the onshore sediment samples particle size analysis

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C.

Appendix C: Offshore sediment samples particle size frequency histograms

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Appendix D: Onshore sediment samples particle size frequency histograms

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<td><img src="image5" alt="Graph" /></td>
<td><img src="image6" alt="Graph" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LRII/9- South of G2</th>
<th>LRII/10- North of G3</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image7" alt="Graph" /></td>
<td><img src="image8" alt="Graph" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LRII/11- South of G3</th>
<th>LRII/12- North of G4</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image9" alt="Graph" /></td>
<td><img src="image10" alt="Graph" /></td>
</tr>
</tbody>
</table>
Particle Size Distribution

0.01 0.1 1 10 100 1000 3000

Particle Size (µm)

0 2 4 6 8 10 12 14 16 18 20

Volume (%)

LRII/23 - South of G8 in Water

LRII/24 - South of G8

LRII/25 - North of G9

LRII/26 - South of G9

LRII/27 - North of G10

LRII/29 - South of G10

LRII/30 - South of G10

LRII/31 - East of G11

LRII/32 - East of Jetty

LRII/33 - South of Jetty

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LRII/34 - West of Jetty

Particle Size Distribution

Variation

Particle Size (µm)

Volume (%)

0.01  0.1  1  10  100  1000  3000

0  2  4  6  8  10  12  14  16  18  20  22  24

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Appendix E: Bathymetry of Lady Robinsons Beach (profiles 1, 4, 8, 12 & 14)

Changing Bathymetry of Lady Robinsons Beach

Cumulative Distance (m)

Depth (m)

Profile 1
Profile 4
Profile 8
Profile 12
Profile 14

Gregory Frost UOW BEnvSc (Hons) 2011
F.

Appendix F: Results from the t-test on the East vs West offshore sediment samples.

<table>
<thead>
<tr>
<th>T-Test</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Difference</td>
<td>19.763</td>
</tr>
<tr>
<td>t-ratio</td>
<td>0.89038</td>
</tr>
<tr>
<td>Std Error Difference</td>
<td>22.196</td>
</tr>
<tr>
<td>Degrees of Freedom</td>
<td>19.31969</td>
</tr>
<tr>
<td>Upper CL Difference</td>
<td>66.169</td>
</tr>
<tr>
<td>Prob &gt;</td>
<td>t</td>
</tr>
<tr>
<td>Lower CL Difference</td>
<td>-26.642</td>
</tr>
<tr>
<td>Prob &gt; t</td>
<td>0.1921</td>
</tr>
<tr>
<td>Confidence Interval</td>
<td>0.95</td>
</tr>
<tr>
<td>Prob &lt; t</td>
<td>0.8079</td>
</tr>
</tbody>
</table>
G.

Appendix G: Results from the t-test on the North vs South offshore sediment samples.

| Mean | Upper CL | Lower CL | Std Error Difference | Degrees of Freedom | Prob > |t| |
|------|----------|----------|----------------------|-------------------|-------|---|
| 300  | 41.301   | -51.715  | 22.509               | 23.50352          | 0.8191|   |

Oneway Analysis of Volume weighted mean (μm) by Sample Site

T-Test

| Difference | t-ratio | Degrees of Freedom | Prob > |t| |
|------------|---------|-------------------|-------|---|
| -5.207     | -0.23133| 23.50352          | 0.8191|   |

Confidence Interval 0.95
Appendix H: Results from the t-test on the Northern Beach vs Southern Beach onshore sediment samples.

<table>
<thead>
<tr>
<th>Difference</th>
<th>17.344</th>
<th>t-ratio</th>
<th>1.119698</th>
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</thead>
<tbody>
<tr>
<td>Std Error Difference</td>
<td>15.490</td>
<td>Degrees of Freedom</td>
<td>23.37914</td>
</tr>
<tr>
<td>Upper CL Difference</td>
<td>49.358</td>
<td>Prob &gt;</td>
<td>t</td>
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<tr>
<td>Lower CL Difference</td>
<td>-14.670</td>
<td>Prob &gt; t</td>
<td>0.1371</td>
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<tr>
<td>Confidence Interval</td>
<td>0.95</td>
<td>Prob &lt; t</td>
<td>0.8629</td>
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</table>
Appendix I: Results from the t-test on the onshore sediment samples from the North vs South sides of the groynes.

<table>
<thead>
<tr>
<th>Sample Site</th>
<th>Volume weighted mean (μm)</th>
</tr>
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<tbody>
<tr>
<td>N_G</td>
<td>320</td>
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<tr>
<td>S_G</td>
<td>375</td>
</tr>
</tbody>
</table>

T-Test

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Difference</td>
<td>52.0470</td>
<td>t-ratio</td>
</tr>
<tr>
<td>Std Error Diff</td>
<td>14.4649</td>
<td>Degrees of Freedom</td>
</tr>
<tr>
<td>Upper CL Diff</td>
<td>82.5549</td>
<td>Prob &gt;</td>
</tr>
<tr>
<td>Lower CL Diff</td>
<td>21.5391</td>
<td>Prob &gt; t</td>
</tr>
<tr>
<td>Confidence Interval</td>
<td>0.95</td>
<td>Prob &lt; t</td>
</tr>
</tbody>
</table>
Appendix J: Results from the t-test on the onshore sediment samples from the South Point (LRII/31-34) vs Further North (LRII/26-30).

### Oneway Analysis of Volume weighted mean (μm) By Sample Site

<table>
<thead>
<tr>
<th>Sample Site</th>
<th>Volume weighted mean (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>-55.242</td>
</tr>
<tr>
<td>S</td>
<td>16.995</td>
</tr>
<tr>
<td>Degrees of Freedom</td>
<td>5.998854</td>
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</tbody>
</table>

### T-Test

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
<th>Value</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Difference</td>
<td>-55.242</td>
<td>t-ratio</td>
<td>-3.25039</td>
</tr>
<tr>
<td>Std Error Difference</td>
<td>16.995</td>
<td>Degrees of Freedom</td>
<td>5.998854</td>
</tr>
<tr>
<td>Upper CL Difference</td>
<td>-13.653</td>
<td>Prob &gt;</td>
<td>t</td>
</tr>
<tr>
<td>Lower CL Difference</td>
<td>-96.830</td>
<td>Prob &gt; t</td>
<td>0.9913</td>
</tr>
<tr>
<td>Confidence Interval</td>
<td>0.95</td>
<td>Prob &lt; t</td>
<td>0.0087</td>
</tr>
</tbody>
</table>