Wooli Beach Erosion: Moving Forwards

A PROJECT PROPOSAL BY:

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A project proposal prepared for

Coastal Communities Protection Alliance-Wooli Inc.

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CONTENTS

TABLE OF FIGURES

1 INTRODUCTION

This document first outlines the initial findings from the review of the recent coastal hazard and management reports (WP, 2010a, b), and a fact-finding visit to Wooli, New South Wales, Australia (Figure 1.1). Based on the findings of the review and fact-finding visit, a proposal to undertake data collection and a coastal process study is described. Wooli has been classified as 1 of 18 erosion hotspots along the NSW coast, and like many other hotspots, the preferred response from the hazard and options assessment is managed retreat. Due to the lack of data, the methods applied to develop hazard lines and the known variables (e.g. sand is accumulating in Jones' Beach south of the training walls, since the training walls were built 1,100-4,400 m^3 is being retained in the estuary each year, submerged offshore structures (both natural and man-made) create salients on this coast, at least 4,000 m^3 is lost to the wind each year, etc), it is likely that management options for Wooli Beach erosion can be applied for at least a 100-year planning horizon. This assessment does not address the threat of river breach at the northern end of the Wooli barrier spit, which could likely be remedied with hard engineering.

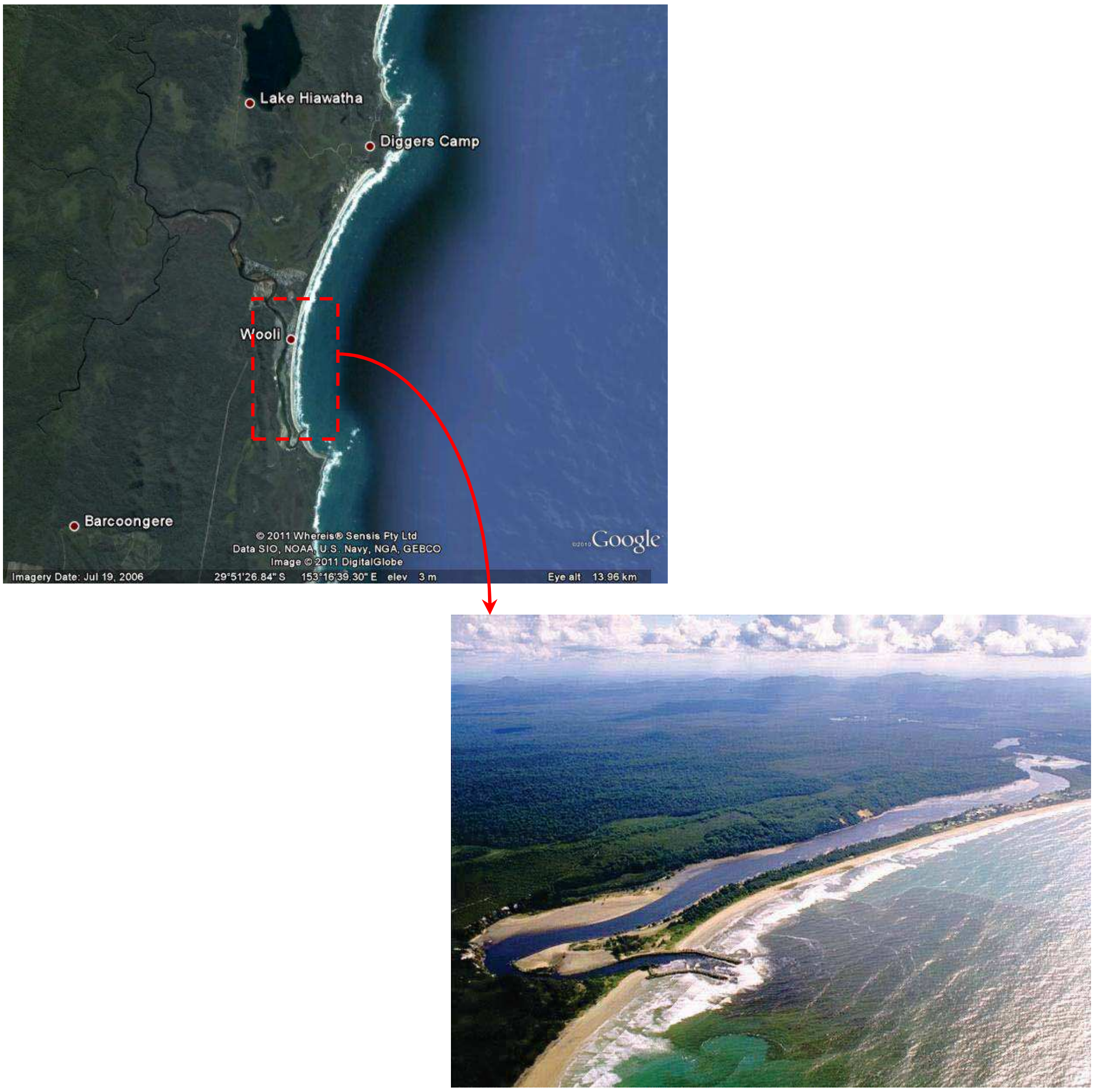


Figure 1.1 Wooli Beach, New South Wales, Australia.

Since it is expected that offshore structures could form part of a beach protection strategy for Wooli, preceding the proposal for a coastal processes study are sections outlining the history, development, uses and benefits of multipurpose reef (MPR) technology, as well as highlighting recent case studies of reef implementation. While this coastal process study is directed at understanding and quantifying the existing processes at Wooli, it is envisaged that any structural solution would incorporate added amenity benefits. MPR's are a relatively new technology, however, they can be considered one step beyond traditional detached breakwaters, designed using state-of-the-art techniques and incorporating amenity and ecological benefits. This is followed by a description of the specific steps required to complete a coastal process study, as well as a preliminary options study to consider the efficacy of different management options.

It is noted that ASR's approach is to coastal issues is to first understand and quantify the local processes and then develop often innovative sustainable solutions (i.e. not particularly multi-purpose reef solutions). In the present case there are a range of factors to be addressed, as well as alternatives such as sand by-passing from the accreting Jones' Beach, reassessing the entrance channel training walls in order to increase velocities and hence sediment supply, and dune planting to reduce wind-blown sand loss.

2 WOOLI SITE VISIT AND FACT-FINDING INVESTIGATION

2.1 Introduction

Three days were spent at Wooli, hosted by Tim and Audrey Heldt. On February 24th 2011, Dr. Mead was taken on a tour of whole beach, starting on the terrace opposite the main wharf area, then down to the river mouth, up to Wilsons Head, and back to the terrace in the vicinity of "One Tree". This was followed by a meeting with Stan at Wooli Deep Sea Tours, where Stan's knowledge of the area was related and marine charts, GPS based digital images and historical aerial photographs were viewed to gain an understanding of physical layout of the local beach and bathymetry. The information gathered was then related to the various reports and background information available.

On February 25th, the various information sources and conclusions drawn from these were compiled into a power-point presentation for a meeting with representatives at the Clarence Valley Council (CVC). The CVC and CCPA agreed to work at identifying ways for the two parties to address the short, medium, and long term challenges presented at Wooli.

On Saturday 26th February Dr. Mead was one of the key speakers at the CCPA public meeting to discuss Wooli and the path forward.

2.2 General Findings

1. Based on based on preliminary observations and the existing information, there is very good scope for targeted management and risk mitigation of beach erosion at Wooli.
2. Wooli beach likely behaves in a similar manner to a very large scale pocket beach, i.e. there is little sand exchange from the adjacent coast;
3. There is an abundance of sand in the system compared with many sites suffering from beach erosion, which is likely due to factors such as ENSO (El Nino Southern Oscillation), the IPO (Inter-decadal Pacific Oscillation), modification of the river entrance and human impacts (e.g. impacts on natural beach vegetation);
4. Wooli is likely to respond favourably to measures to manage sand distribution provided this is done to work with the natural processes;
5. Wind erosion of the beach is probably a more significant issue than is generally realised (it is currently estimated that at least 4,000 m^3 is lost to the wind each year). Evidence on the beach is that appropriate dune vegetation can significantly enhance sand retention. This is a very economical and simple mitigation measure;
6. There is a very limited quantified data set upon which to base scientific assessment of erosional trends and beach processes at Wooli.
7. Some relatively simple and available monitoring techniques could be applied at Wooli, which over time would substantially improve the scientific basis for decision making (e.g. quarterly beach profiling combined with digital image capture from appropriate locations should be considered).

8. The positive influence of near shore reefs is evident in the beach morphology and aerial photographs of the beaches on this part of the coast. Thus, it is feasible to incorporate manmade reefs to influence sediment transport at Wooli Beach as part of a beach protection strategy.
9. The training walls are having an influence on sand movement along the beach, as is evident by the sand reservoir building up on its southern side in Jones' Beach. This resource could be very helpful to help with mitigation strategies (e.g. bypassing to the north).
10. The training wall's presence may also have subtly influenced the beach plan shape by modifying the southern beach control point. As a result, the beach may have retreated in the area of Wooli village to reach a new equilibrium.
11. Since the training walls were built 1,100-4,400 m^3 is being retained in the estuary each year.

2.3 Existing Knowledge and the Development of Coastal Hazard Lines

The history of Wooli Beach has included a range of impacts that have influence sand supply and beach plan shape, although there is little data to quantify these impacts:

1. Sand-mining (volumes and dates?)
2. Windblown sand loss (>4,000 m3?)
3. Alongshore sand loss (~40,000 m3?)
4. Offshore sand loss (??)
5. Training wall impacts (retaining sand in the estuary, retaining sand in Jones' Beach, readjustment of the beach plan shape in response to the modified southern control point)
6. The rocking response (due to prevailing storm directions, detected in historical aerial photographs).

The recent Coastal Hazard Assessment and companion Coastal Management Strategy Update and Options Review (WP, 2010a, b) can be considered updates on the 1997 studies by Patterson Britton & Partners Pty Ltd (1997a, b). Unfortunately, there is scant data for Wooli Beach, with much of the assessment reliant on time series aerial photographs. While this technique is a valid, useful and widely used technique, the 'rocking' response of Wooli Beach due to the effects of ENSO means that it is difficult to determine linear trends in beach movement. Indeed, the additional understanding of the beach response due to ENSO (Ranasinghe et al., 2004), is the main update from the 1997 assessment. In simple terms, when southern storm events dominate (El Nino), the beach sand is pushed northwards filling Wilson's Head and eroding the Wooli Village area, and when northerly storm events dominate (La Nina), Wilson's Head is eroded and accretion occurs in the Wooli Village area. Following the series of northerly events over this summer, Wilson's Head has retreated some 40-50 m since last summer, while the southern part of the beach is wide and 'healthy' (Figure 2.1).

Thus, quantification, and possibly identification of erosional trends are difficult to determine from 6 snapshots in time (i.e. aerial photographs) between 1947 and present.

Figure 2.1. Top: Wilson's Head actively eroding (24 Feb 2011). Bottom: the southern end of Wooli Beach actively accreting (24 Feb 2011).

Much of the concerns with respect to the managed retreat for Wooli have arisen due to the conservative method of beach recession applied in the Coastal Hazard study (WP, 2011a). The NSW guidelines for coastal hazard zoning offer the Bruun Rule for the determination of shoreline recession due to sealevel rise. However, this method is very basic and has assumptions that do not apply to Wooli, nor indeed most beaches world-wide. The Bruun Rule is applied because it is easy to use and provides a conservative estimate of beach recession. However, there is little data to support its application; indeed, there are very few examples world-wide where it has been successfully validated (Cooper and Pilkey, 2004). Although Huxley's (2009) numerical methodology for determining beach recession is mentioned in the WP (2011a) Coastal Hazard study, the results are not applied, since this work is also unsupported by data because there is no applicable data available for Wooli Beach. It is notable that Huxley's (2009) beach recession estimates that consider scenarios with beach rotation and apply far more sophisticated methodologies than the Bruun Rule are of the order of 12 m recession with a 0.6 m sea level rise (estimated to be 2070), while the WP (2011a) recession estimates for 0.4 m (2050) and 0.9 m (2100) sea level rises are 20 m and 45 m, respectively.

The important point that was clarified by the CVC is that the current Coastal Hazard zones are the first order estimates; the next stage is emergency response planning, then medium term planning and long-term planning. Thus, the focus of the CCPA beach protection strategy for Wooli should be to ensure the beach is widened and protected for a 100-year planning horizon. This will require collection of data and development of modelling tools to understand and quantify the existing beach processes and assess the efficacy of management strategy components.

2.4 Wind Blown Sand Loss

Sand lost landwards due to onshore winds has often been overlooked as part of beach management strategies. Sand dunes are the coasts natural form of coastal protection and when they are "healthy" coastal protection structures are often not required. This requires the introduction of appropriate plant species and defined access/walkways over the dunes to maintain their health. In the past 2 decades, methods of propagating native sandbinders have been developed in New Zealand with very good results country wide. Grazing by cattle and rabbits, and burn-offs led to the loss of much of NZ's natural dune species (spinifex and pingao). Their reintroduction through Coast Care groups has led to the development of 'natural' dunes where previously there were none (Figure 2.2). These plants capture wind-blown sand and grow shorewards and upwards to create wide rolling dunes, rather than very steep dunes that are more vulnerable to wave attack. It terms of coastal erosion, this is in fact the preference, since rather than waves attacking a steep wall of sand and 'eating' into it and removing sand offshore, waves can run-up the dune and percolate thru the sand with a much reduce back wash. In addition, native dune plants can be fully inundated with seawater without dying, while terrestrial plants in the same location will die if inundated with seawater.

In other parts of the world, removal of exotic and non-foredune species is now becoming a useful practice for coastal management. This area of coastal management (dune stabilization with appropriate coastal species) requires investigation for the Wooli Beach. There is evidence that where spinifex is present on the beach, there is development of natural foredunes, as well as the possibility of competition between these plants and terrestrial plants that cannot cope with seawater inundation (Figure 2.3). Dune stabilization could be part of a hybrid solution for coastal protection at Wooli; these methods are far more effective than a ‘single fix’ approach; e.g. combining sand-retention structures, beach renourishment, buried revetments and dune stabilization provides a far more robust solution.

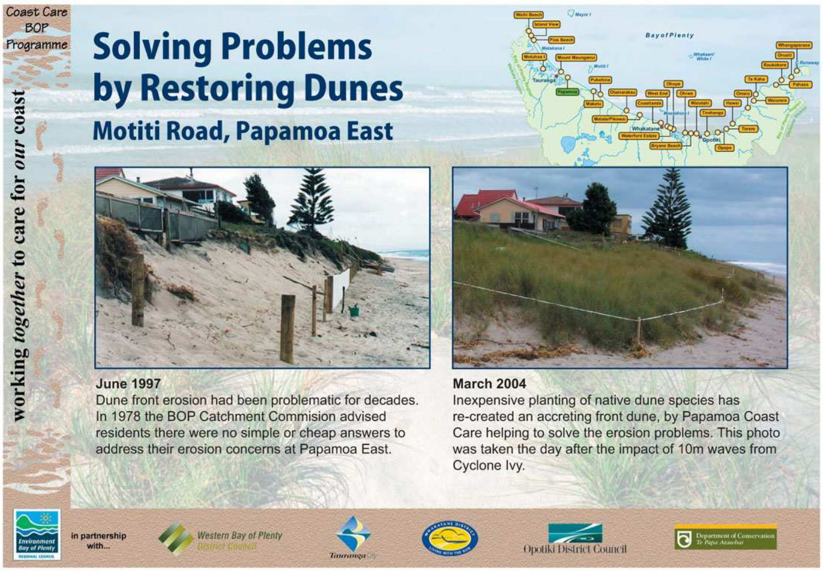


Figure 2.2. Dune stabilization with native dune species in northeastern NZ.


A


B

Figure 2.3. A. Foredune formation where there is spinifex. B. Competition?

2.5 The Entrance Training Walls

The training walls at the entrance of the river have likely had at least 3 impacts on Wooli Beach:

1. Trapping of sand in Jones' Beach (i.e. less sand reaching the main beach system).

2. Reducing the amount of sediment supplied by the river to the beach.

3. Led to a subtle readjustment of the beach orientation.

The trapping of sand in Jones' Beach can be used as a source of renourishment material to intermittently supply the area along the Wooli Village, although to be sustainable in the long-term, it is likely that the rate of sediment transport both offshore and alongshore would need to be reduce with the aid of structures and dune stabilization.

There is anecdotal evidence and it is estimated 1,100-4,400 m^3 of sand is being retained in the estuary each year since the construction of the training walls. These walls were constructed some 50 years ago, without the aid of the coastal engineering tools available today (e.g. numerical models). Thus, a potential increase in sand supply to Wooli Beach could be ascertained by revisiting the current training wall design and considering options that would aid the flushing of sediment out to the beach during flood events.

Another possible effect of the training walls is the subtle readjustment of the beach plan shape. While there are many offshore complexities at Wooli to blur the beach response, beaches tend towards a natural curve (often considered a log-spiral). The construction of the training walls led to the southern control point of the beach, of the previous river delta being pushed offshore some 100 m, effectively compressing the length of the main beach compartment. As a result, the beach would readjust by a slight 'deepen' of the previous natural curve (e.g. Pickrill 1979).

2.6 Offshore Sand Loss

Along the northern coast of NSW, there is evidence of chronic erosion, which has to a large extent been attributed to the offshore loss of sand during intense storms, with the inability for these sediments to be transport back shorewards following the events (due to them being a depths too great for mobilization, or past the depth of closure). Detached structures are the most effective at reducing this type of sediment transport US Army Corps of Engineers, 1995). Along this coast there are many examples of natural reefs creating salients (wider beaches) in their lee (Figure 2.4). Indeed, the development of empirical formulas to predict the beach response to structures was developed from natural situations on the east coasts of NSW and New Zealand (Black and Andrews, 2001a, b). Thus, there is good evidence that offshore submerged structures could be part of the long-term management strategy to ensure that Wooli Village retains a wide beach in front of it to protect it from storm events and the effects of sealevel rise.

Figure 2.4. A natural salient behind an offshore reef at Safety Beach. There are many other examples along the NSW coast.

2.7 Data Collection Moving Forwards

There is little data available with respect to beach trends for Wooli Beach, which has been impacted by the training of the river entrance at the southern end and other human developments. Collection of times series data of beach state/position provides very important information with respect to long-term trends and beach response (erosion or accretion) to different types of events. Simple and cost-effective methods to collect these types of data include:

- Beach profile surveys
- Automated photo/video collection

Beach Surveys

Once bench marks are established for each profile, this is a relatively easy and cost effective method of recording beach changes using standard land survey equipment (e.g. a total station). While the more data the more often is always best, bimonthly or quarterly surveys would be adequate, with the addition of post-storm surveys if possible. Profiles positioned 200 m apart along the length of the Wooli settlement, with wider spacings (400-500 m) along the other parts of the beach would be more than sufficient (Figure 2.2). This equates to some 22 profile lines. It is likely that follow a comprehensive comparison of profile surveys to the rectified camera images, many of the 200 m spaced profiles that are in the camera's field of view would not need to be surveyed.

Camera Data Collection

Collecting hourly images and/or video clips is a very effective method of beach data collection. Commercial systems such as the ARGUS system (e.g. as used at the Gold Coast Reef – Appendix 4) or Cam-Era have been in operation for more than a decade. Cameras are positioned in a stable location as high as possible above the beach (e.g. the water tower at Wooli), and images are collected and either stored or sent to an ftp site. Images can then be rectified and a variety of analysis techniques can be applied to develop a quantified understanding of beach response and trends. While there are commercial systems available, with today's technology there are many options such as an HD video camera in a housing using a smart-phone to transmit images, or a HD webcam sending images/video straight to the internet (as with many of the surfing forecast sites worldwide). As long as the images are of high enough resolution and the camera location and elevation along with sufficient image control points are known, the rectification process can be simply applied. For example, ASR runs a very simple automated system at its technical headquarters in Raglan, New Zealand. Hourly images from high above the beach and harbour entrance are posted on www.snow.co.nz which are automatically downloaded to ASR's server, automatically rectified and added to an archive tool that allows the user to visually assess the time series data, fit curves and trend lines to the harbour delta, match time series video of any period of time to the coincident wave and wind data, etc (Figure 2.3). These rectified images also provide a great deal of information on beach processes with respect to the surf-zone, which can be used to infer bars, rip-cells, etc.

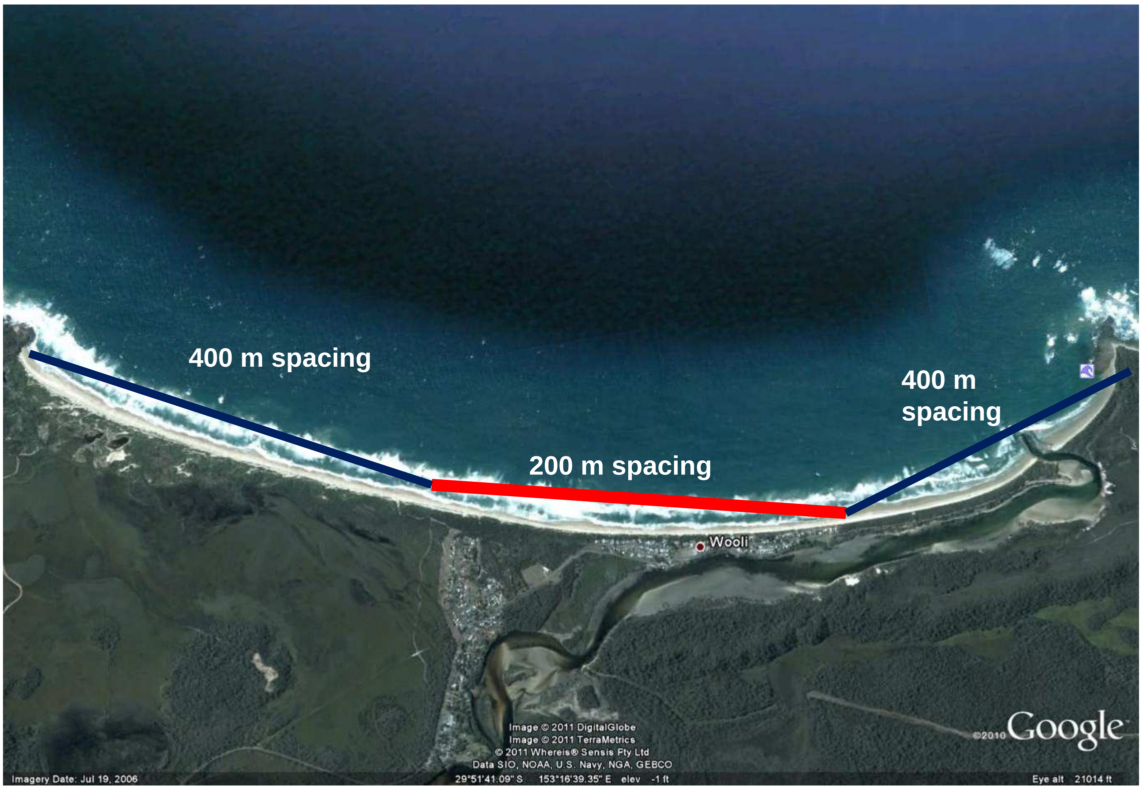


Figure 2.5. Beach profile spacings along Wooli Beach

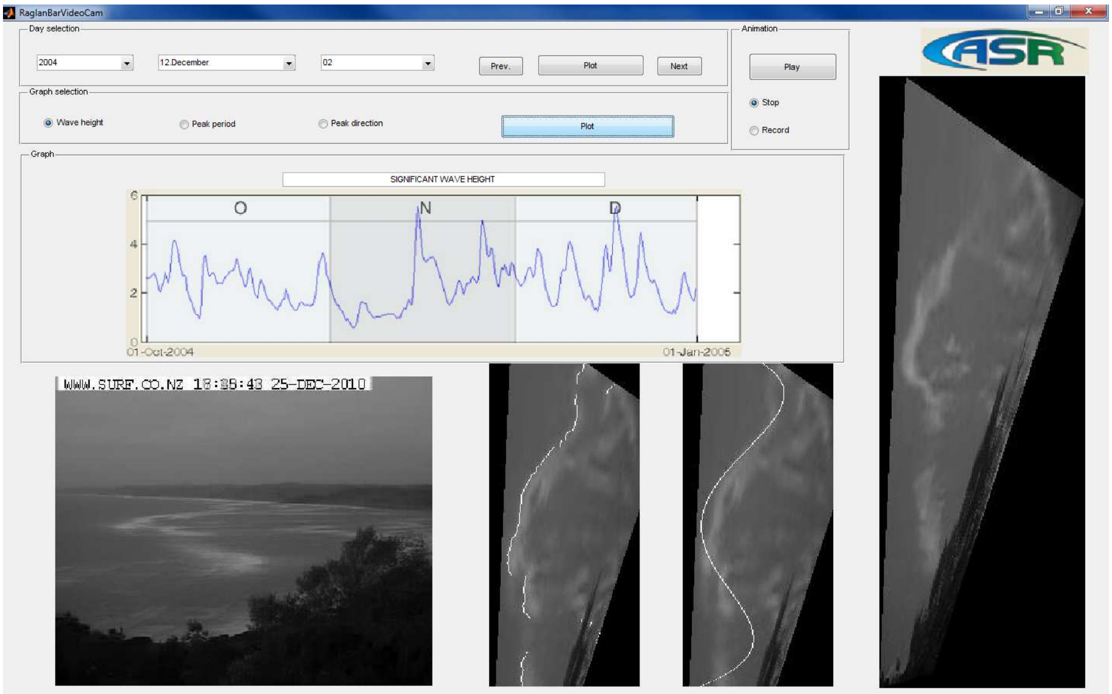


Figure 2.6. Screen capture of the GUI that allows viewing and analysis of the Raglan Bar camera images.

2.8 Potential Beach Protection Strategy for Wooli Beach.

From the above discussion, a potential BPS for Wooli Beach could include:

- Offshore structures;
- Dune management, and;
- Intermittent sand bypassing

This hybrid solution, incorporating a range of management options would be designed to result in a wider beach in the area of Wooli Village. The offshore structure(s) acts to create a salient(s), the dune management helps retain wind-blown sand and build foredunes, while the sand reservoir at Jones' Beach can be used to recharge the beach as required (e.g. following an extreme storm event or series of storms). At present this is a possibility – understanding and quantification of the existing coastal processes is required to develop a long-term sustainable BPS. By developing quantified knowledge of the existing coastal processes, a sustainable BPS can be developed with the aim of widening the beach and thus moving the current hazard lines more seaward and redefining them we good data and science.

3 MULTI-PURPOSE REEFS (MPR'S)

3.1 Background to the Development of Multi-Purpose Reefs

In 1995, the Artificial Reefs Program (ARP) was initiated at the Centre of Excellence in Coastal Oceanography and Marine Geology, a joint graduate school in the University of Waikato and the National Institute of Water and Atmospheric Research (NIWA), in Hamilton, New Zealand. By unifying senior scientists and experienced industrial partners, the ARP aimed to:

- enhance the coastal amenity value of developed shorelines by evaluating multiple use options (surfing, diving, recreational and commercial fishing, navigation and swimming safety) for incorporation into coastal constructions, while also;

- focusing and further developing expertise within the research community, and within private industry, and provide a sound basis for senior student education.

A team of scientists and industry experts were involved including biologists, physicists, engineers, planners and environmental managers, so that both the environmental aspects and the coastal processes could be fully investigated to enable the complete development of multi-purpose reefs. A series of related studies provided the input into the broader program so that offshore protection works could be constructed that incorporate the proposed concepts into their structural designs to fulfil the demands and requirements of the marine environment, recreationalists and developers.

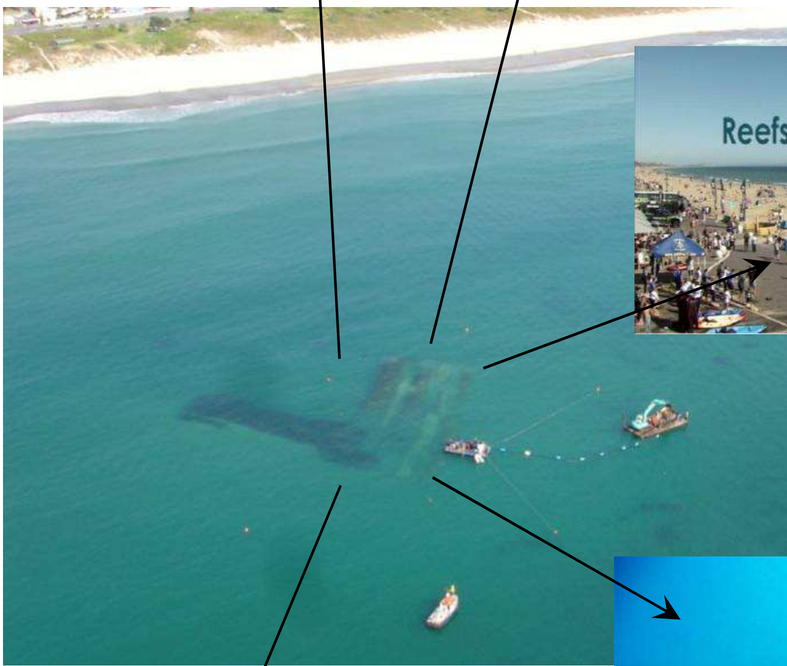
ASR was founded in 1997 with an aim of applying existing and up-to-date knowledge of coastal processes to coastal issues and developments. Over a decade later, ASR Ltd represents the commercial offshoot of the ARP, and although selected graduate students are still involved in the ARP (with joint supervision from ASR Ltd and a University), the primary aim of the Program has been achieved. Indeed, in addition to numerous research theses, individual journal and conference papers and consulting reports, Special Issue No. 29 of the Journal of Coastal Research (Winter 2001), "Natural and Artificial Reefs for Surfing and Coastal Protection" includes more than a dozen scientific papers on the design, impacts and construction of multi-purpose reefs (a second multi-purpose reef JCR Special Issue is currently in press). The public's demand for beaches for recreation, combined with the increasing value society places on the natural environment, has led to a dramatic increase in the development of submerged reef projects world-wide (e.g. Ahren and Cox, 1990; Hsu and Silvester, 1990; Pilarczyk and Zeidler, 1996; Hall and Seabrook, 1998; Black et al., 1998; Harris, 2001; Mead et al., 2003; Babtie, 2003), and more recently independent research is strongly supporting the findings of the initial ARP (e.g. Nielsen, 2001; Houston, 2002; Pilarzyck, 2003; Ranashinge and Turner, 2004; Jackson et al., 2005; Ranashinge et al., 2006; Blacka, 2009).

ASR have developed technology and patented concepts relating to both the design and function of offshore submerged structures (wave rotation) and construction methods that address the physical processes responsible for erosion and the restraints of traditional engineering, as well as incorporate surfing amenity. ASR has proposed designs for over 40 multi-purpose reef projects around the world and has recently completed construction of multi-purpose structures at Boscombe, England and at Kovalam in India. MPR's represent around 1/3rd of ASR's project base, with a wide range of physical and ecological, coastal and estuarine projects making up the other areas of expertise and projects.

The Multi Purpose Reef Concept

Amenity Enhancement: Surfing, Diving, Safe Swimming

Coastal Protection Inspired by Nature



Minimal Aesthetic Impacts

Ecological enhancement

Construction materials have a low carbon footprint

3.2 Coastal Structures

Submerged structures for coastal management are not a new technology, indeed, they have been used for coastal protection throughout the world for many years and remain an active topic of research in the coastal engineering community. What **is** relatively new are the methodologies of design utilizing calibrated numerical models to assess functional performance, the incorporation of surfing amenity and in some cases, species specific habitat enhancement.

Internationally, submerged structures (i.e. submerged breakwaters, artificial or multi-purpose reefs) are being held up as the *environmentally-sensitive solutions* to coastal protection. Research into the application of submerged structures has also increased. For example, in May 2004, the NATO community funded a workshop in Varna, Bulgaria focussed on this topic. The result was a preoceedings volume entitled “Environmentally Friendly Coastal Protection: Proceedings of the NATO Advanced Research Workshop on Environmentally Friendly Coastal Protection Structures”. The proceedings included papers detialing the descriptions and application of a variety of reef structures, i.e.:

- Performance of Submerged Breakwaters as Environmental Friendly Coastal Structures. Sevket Cokgor and M. Sedat Kapdasli
- Low-Crested Structures: Boussinesq Modeling of Waves Propagation P. Prinos, I. Avgeris and Th. Karambas
- Interaction of Waves and Reef Breakwaters. Valeri Penchev
- Flow Measurements and Numerical Simulation on Low-Crested Structures for Coastal Protection. Pedro Lomonaco, Cesar Vidal, Iñigo Losada, Nicolas Garcia and Javier Lara
- Performance of Submerged Breakwaters as Environmental Friendly Coastal Structures. Sevket Cokgor and M. Sedat Kapdasli.

More recently, the European community has launched the THESEUS project, an EU wide initiative aimed at the development of innovative coastal defence technologies, including the use of submerged structures for erosion control. Furthermore, in the United States submerged structures are being considered by the US Army Corps of Engineers as part of their Section 227 erosion control initiative (ASR is currently undertaking detailed design for one of these projects in Ventura, California) and the State of Florida is hosting a special workshop focussed primarily on innovative methods of shoreline protection.

Multi-purpose reefs can be part of an integrated beach management solution. These strategies may also include the combination of sand re-nourishment and dune stabilization through the planting of native dune species such as spinifex and pingoa. Unlike traditional coastal structures whose goal is to protect land (not beach!) and infrastructure; multi-purpose reefs are a solution that aim to maintain and enhance coastal amenity values, particularly a wide sandy beach, since after all, the best form of coastal protection is a healthy beach. In the present case, incorporation of an MPR into a channel stabilization structure may be a feasible way of adding amenity and the subsequent socio-economic returns.

3.3 Surfing Amenity Design

As described above, multi-purpose reefs were developed to address a need for a form of coastal protection that was both environmentally and socially sensitive. However, a large body of science has been directed at understanding natural surfing breaks and designing high-quality surfing amenity into submerged reef. ASR's consultants have been at the forefront of surfing science; with the majority of its employees being surfers and oceanographers. A review of the progress in surfing science is attached as Appendix 1 (Mead, 2003). Together with ASR's 3DD Suite of numerical models (Appendix 2), which have recently been made commercially available, ASR are the world-leaders in surfing reef design – a table of relevant coastal development projects (mainly multi-purpose surfing reefs) that ASR have undertaken in recent years, and further project experience is attached in Appendix 3.

Wave response to submerged structures is entirely dependent on the local, site-specific processes, and so "one size does not fit all". Thus, a thorough understanding of the site is required in order to ensure that the design will perform optimally in terms of providing coastal protection and beach stabilization and the best quality surfing waves under the widest possible range of conditions. This is achieved though the collection and analysis of detailed, on-site oceanographic data followed by application of numerical models to combine the various sources of existing data, experience and the application of the available research.

The following figure sequence shows how the computer generated design of the Mount Maunganui surfing reef was modified through physical modelling in the ASR wave basin to meet the constraints of the sand-filled geotextile containers used in construction.

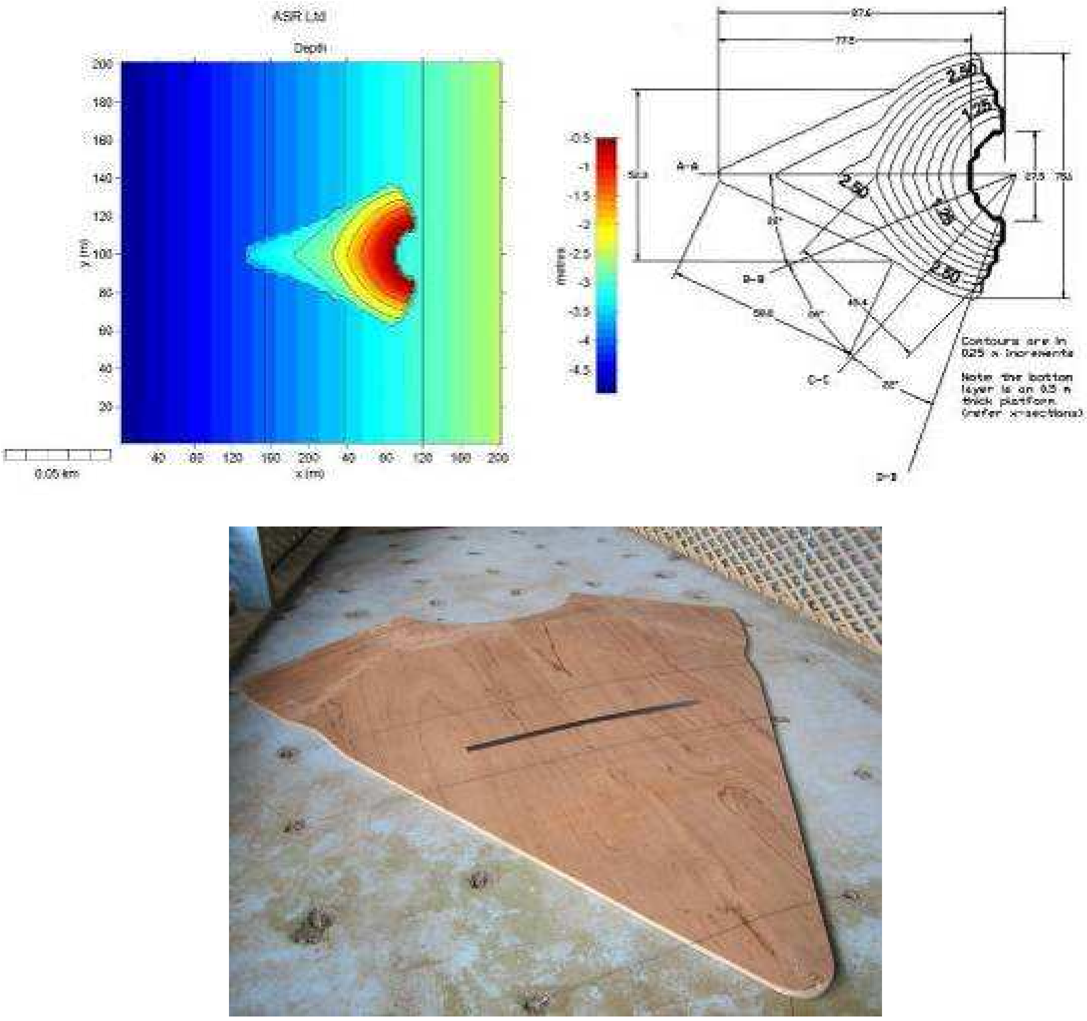


Figure 3.1 The computer generated design of the Mount Maunganui Reef was recreated in great detail using a plywood structure.

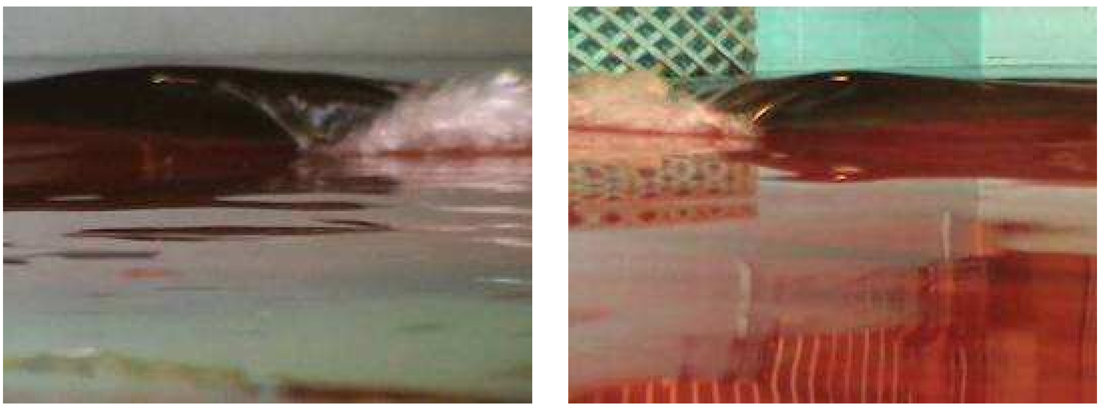


Figure 3.2 This shape was used to perform initial tests in the wave tank and resulted in high quality left and right hand breaking waves.

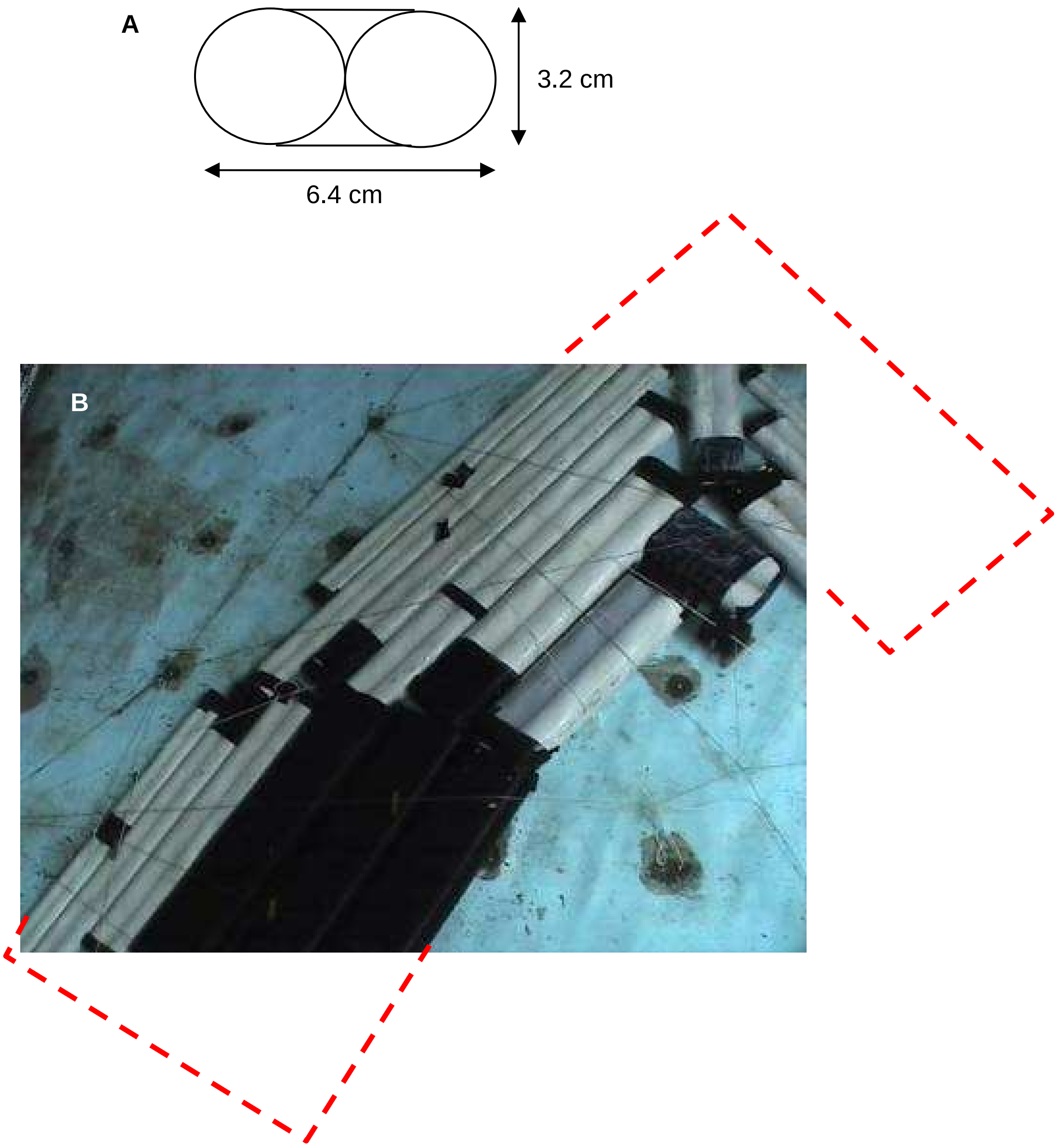


Figure 3.3 (a) Readily available PVC pipe of a variety of sizes was used to mimic the shape of the sand filled geotextile tubes. (b) Updated model of the Mount Maunganui reef. Dashed lines indicate the extent of the model.

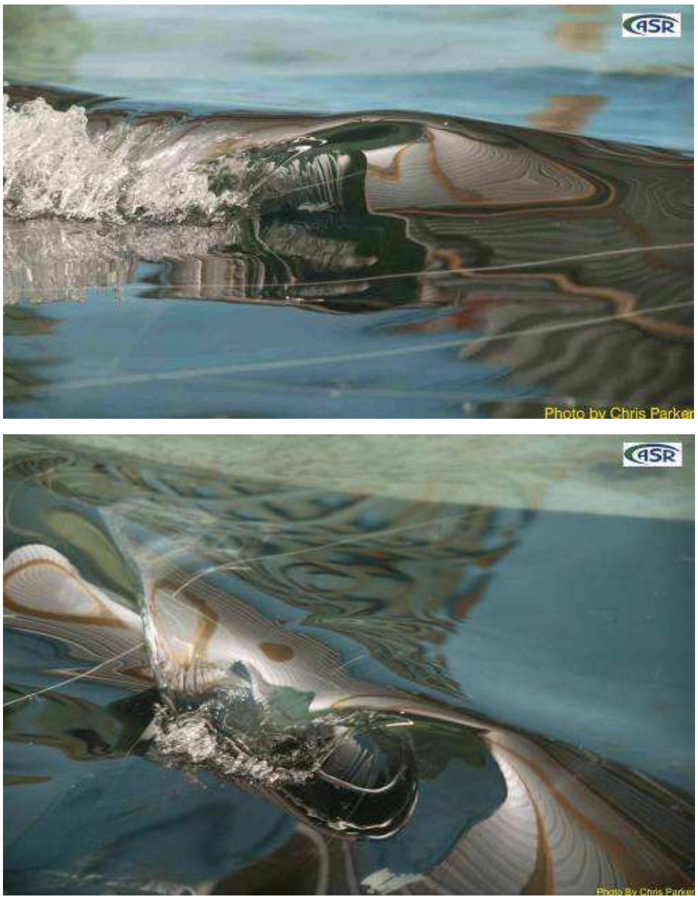


Figure 3.4 After some modifications, the revised model also produced high quality results.

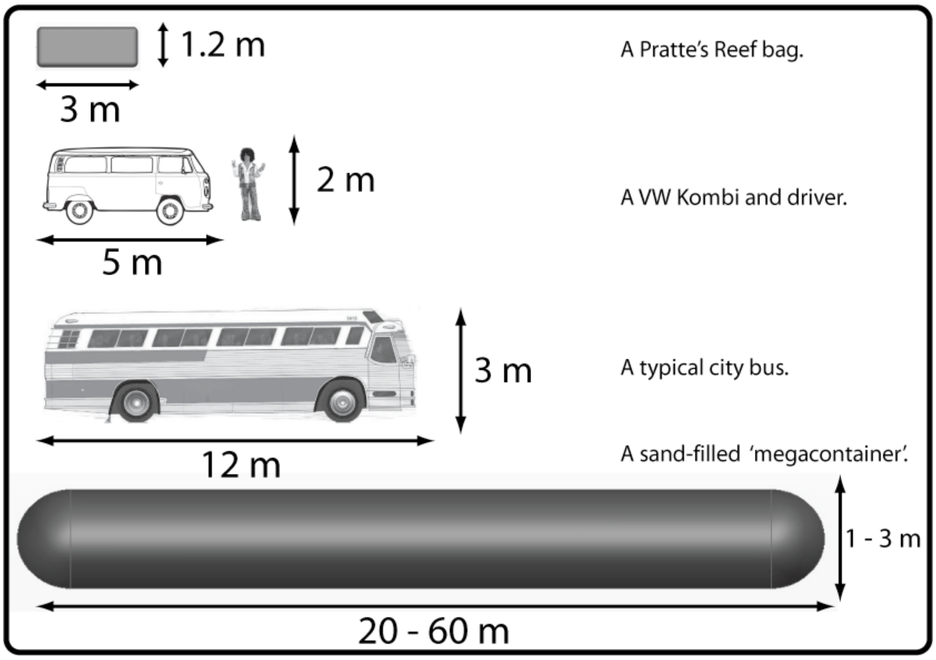


Figure 3.5 Scale comparison of sand filled geotextile containers.

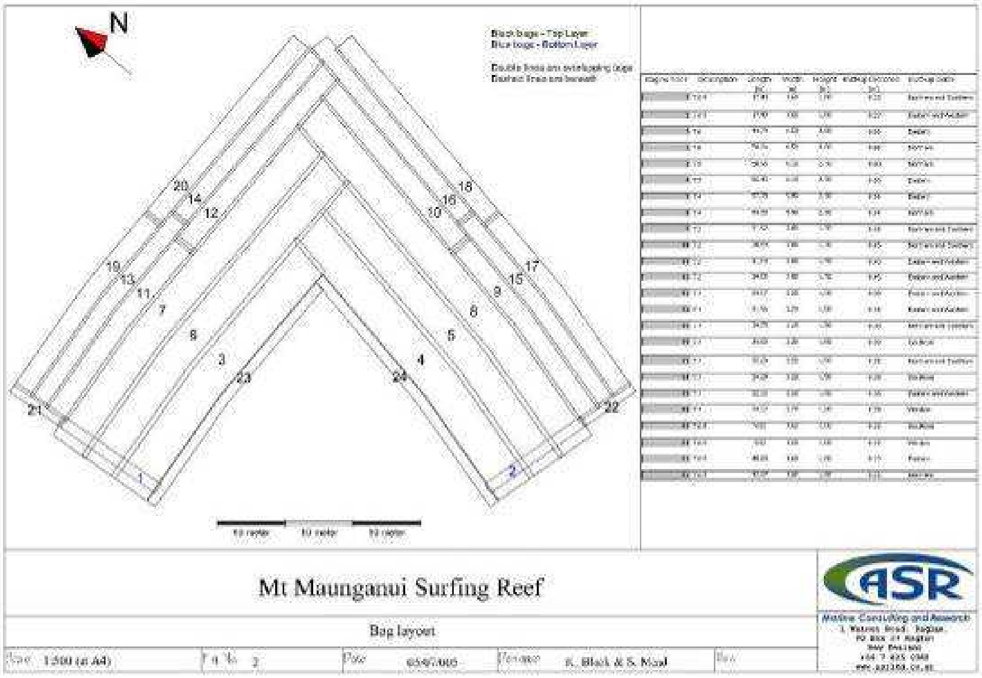


Figure 3.6 Final geocontainers layout plan based on model testing.

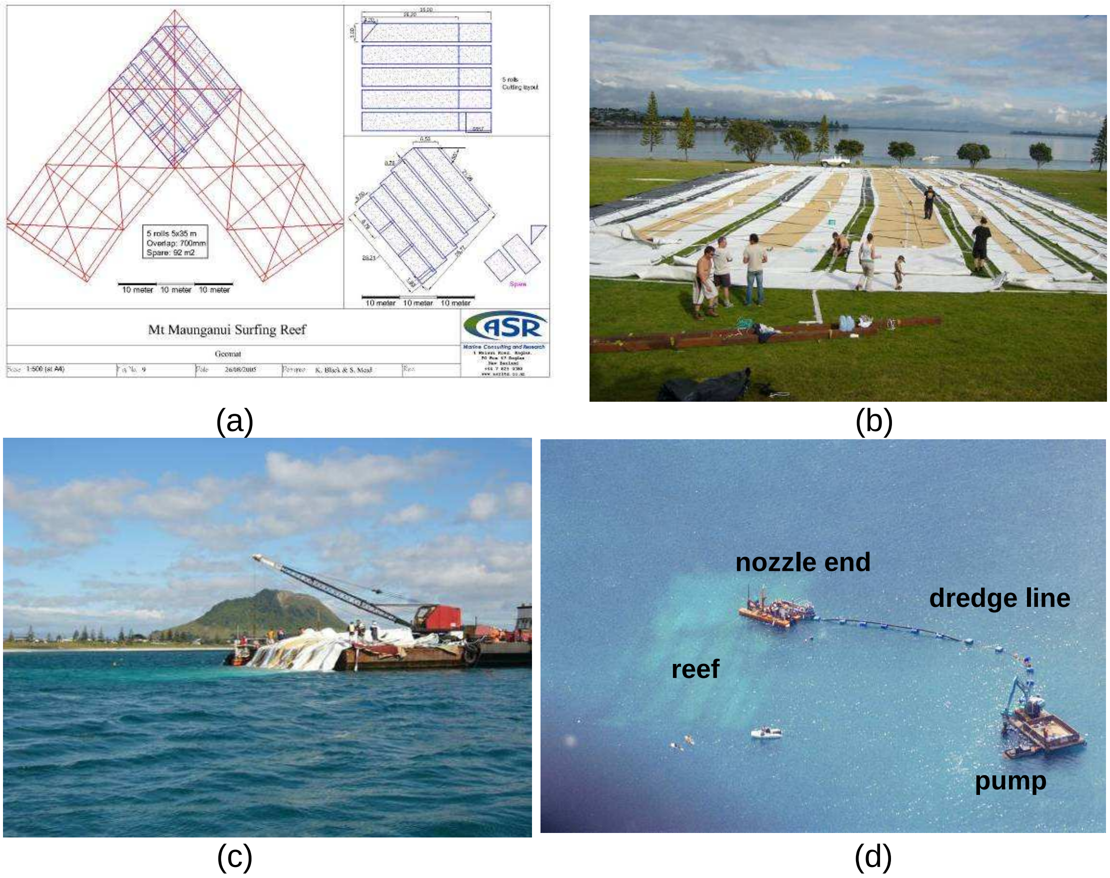


Figure 3.7 Construction of the Mount Maunganui Multi-Purpose Reef. (a) The web design for the Mount Reef. (b) Attaching SFCs to the web. (c) Winching the reef to the seabed. (d) Filling the SFCs.

Figure 3.8 Surfing on the Mount Reef

3.4 Multi-Purpose Reefs and Ecological Enhancement

Locally enhanced biodiversity is a serendipitous side-effect of multi-purpose reefs. This fact provides an added benefit to many areas in the form of an added attraction such as a diving and/or snorkelling site. One such example is the Gold Coast Reef where a local tourist operator includes the reef as part of the dive-trail (Appendix 4).

In ecological terms the principles are simple and well known; hard stable substrate, such as a reef, results in greater biodiversity and species abundance than mobile sandy substrates (Pratt, 1994). Comparatively few species (normally mostly marine worms, crustaceans and bivalves) inhabit the abrasive, mobile seabed provided by sandy sediment, than stable complex reef habitat. The first known use of artificial reef structures for habitat enhancement dates back to the Egyptians in 500BC. More recently there has been a large amount of work on ecological enhancement using artificial reefs throughout the world (e.g. Bulletin of Marine Science, 1994). From these studies it is evident that, as a general rule, species abundance and diversity are greater when the habitat is more stable (in comparison to mobile substrates – e.g. Mead *et al*., 1998), topographically more complex (a higher number of different niches and spaces are available) and when the reef is larger (Pratt, 1994). Construction of artificial reefs also provides the opportunity to create specific habitat and 'seed' specific species that may be of commercial or cultural value. For example, in Japan artificial reefs are constructed for sea urchin fisheries enhancement (Saito, 1992). Therefore, the biological enhancement due to the construction of a multi-purpose reef may include increased environmental value (increases in bio-diversity and abundance), increased amenity in the form of a diving and snorkelling venue, and enhanced fisheries by the incorporation of specific habitat.

Like surfing reefs, where only occasionally do the factors all come together to make a high-quality surfing break, the same is true of habitat for specific species. Indeed, it seems that the majority of species in the oceans are not limited by their number of offspring, but by the availability of habitat for them to colonise and inhabit (Pickering and Whitmarsh, 1996) – there may be 100's of thousands of larvae in the water, but no suitable substrate to settle and colonise. Creating reefs presents the opportunity to incorporate specific topography for specific species, which opens opportunities for fisheries management, reserves and recreational amenity. Many marine organisms of the intertidal and shallow subtidal zones are far more capable of responding and adapting to physical change than the flora and fauna that inhabit the land, since they live in a comparatively harsher physical environment. The Narrowneck reef on the Gold Coast reef is a good example of this. Rapid colonisation of the reef after construction quickly resulted in a diverse reef ecosystem, in fact, more than 270 different species have been identified living on and around the Narrowneck Reef – similar results have occurred at the Mount Reef. As a result, the reef and surrounding area have now become a popular fishing spot as well as hosting a dive trail and a snorkelling site for tourists (http://www.divingthegoldcoast.com.au/index.asp?PageID=narrow).

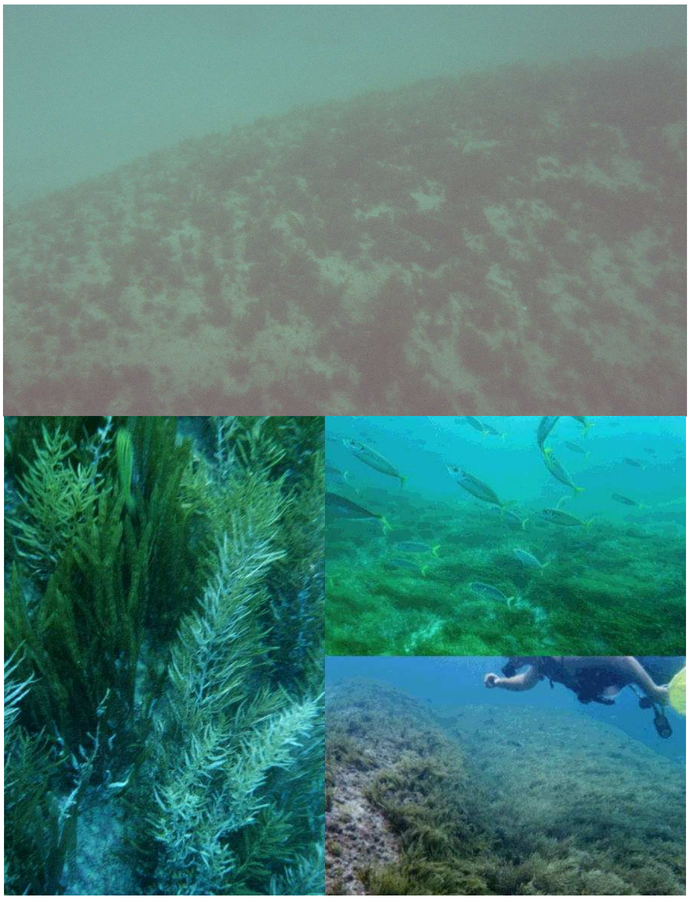


Figure 3.9. Colonisation by seaweeds began the moment the Gold Coast multi-purpose reef was under construction (top – 2 weeks old). Over 2 years later, a large variety of marine life inhabits the reef.

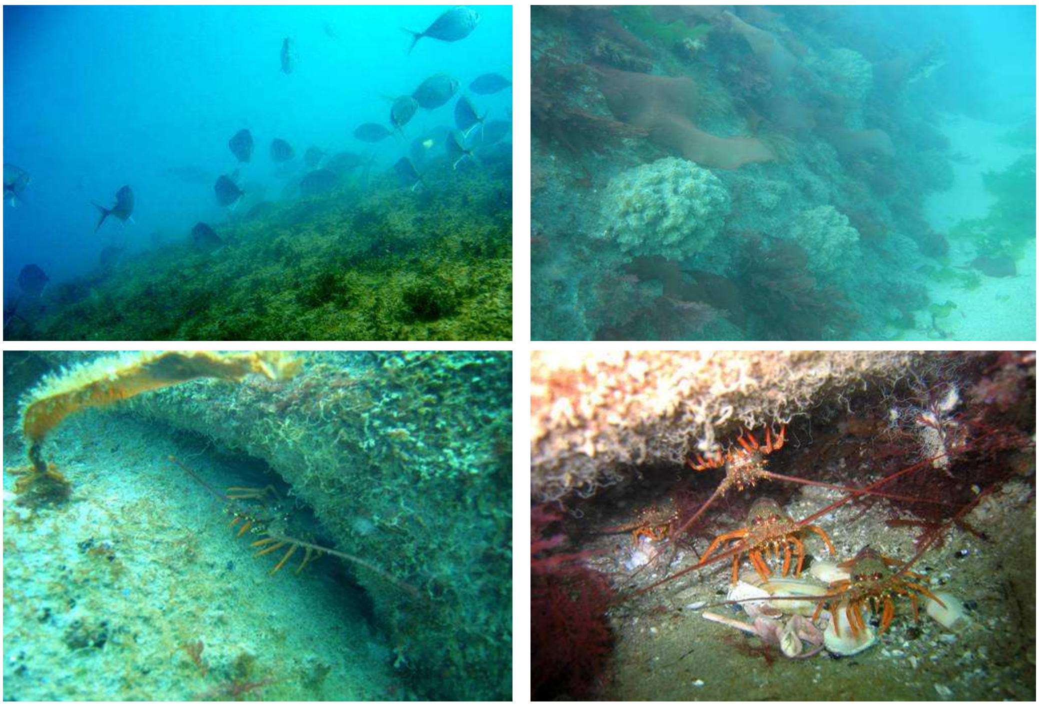
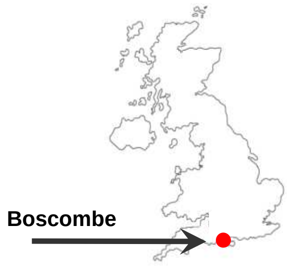


Figure 3.10 Similar colonization patterns have been observed at Mount Maunganui

The reef itself provides a substrate for larval organisms in the water column to settle on and become established. Once primary producers become established, these organisms, and the reef itself, provide shelter and a food source for fish and other marine life and act as a fish aggregating device (FAD) (Bohnsack & Sutherland, 1985). In addition, a reef may also subtly alter the local hydrodynamics in a way that could increase settlement in the lee of the reef (e.g. Black & Gay, 1987). In some cases, where biological enhancement is considered a value component of a multi-purpose reef project, biodiversity can be further increased by the incorporation of purpose-built structures in the lee of the reef, such as Reef Balls. These structures add further habitat complexity and shelter for a variety of reef fishes and invertebrates.

Figure 3.11 Further complexity can be incorporated into a multi-purpose reef to increase biodiversity, such as the Reef Balls shown here (www.reefballs.com).



3.5 *Design, Construction and Outcomes of the Boscombe Reef*

3.5.1 Introduction

The following brief project summary provides some insight into the use of multi-purpose structures for social and economic enhancement, as part of a broader project. The Bournemouth Borough Council (BBC) commissioned ASR Ltd. to develop a multi-purpose reef for recreational and commercial benefit in Boscombe. The aims of BBC were to apply multipurpose reef technology to enhance surfing at site which at present only provides mediocre surfing conditions. By developing a better quality surfing venue, the Borough Council believed that it would not only benefit new generations of surfers but also provide a unique focus for the region and the Boscombe Spa development. ASR conducted extensive field studies which collected wave, tide, bathymetric and ecological data as part of the Boscombe Reef design project. The challenges of working with a small and unpredictable wave climate were overcome by creating a design with a large footprint that could magnify and make the most of even the smallest and least favourable wave conditions. The final design called for a reef volume of approximately 13,000 m^3 to be built from approximately 50 large sand filled geotextile containers. ASR Ltd commenced construction of the Bournemouth Reef in July 2008. The first layer of the structure was built in the first construction season (summer 2008) with the remainder of the reef completed in second construction window during the summer of 2009. The project has won UK tourism and development awards.

3.5.2 Nearshore Environment and Design Criteria

Boscombe is located in the western English Channel on the south coast of England, approximately 150 km, southwest of London. Due to its location, Boscombe is sheltered from the large swells of the North Atlantic Ocean. Frequently however, local winds produce short choppy seas affecting the area. Despite the adverse conditions for recreational wave riding, surfing is nevertheless a popular activity here with the third largest surfing population in the UK.

Since multi-purpose reef design projects are limited by physical and economic constraints, the design must take into account a wide range of factors to obtain the optimum solution for a particular location. At Boscombe, the key factors investigated as part of the iterative reef design process were the wave climate, the wind climate and the crest height.

For the design process, a detailed bathymetric surveys was conducted at the proposed reef site. Wave data was collected from both a waverider directional buoy located 1 km offshore of the Boscombe Pier and supplemented with a 6 week deployment of an in-situ wave and current meter in 5 m water depth at the proposed reef site (Figure 1 a). Wave transformation studies were conducted between the two data sets to establish an inshore wave climate for the design process. The design wave conditions for the reef were for H_{10} = 1 m ± 0.5 m; T = 7 s ± 2 s , and wave direction coming from 191ºN ± 6º.

Water level information was derived from a tide gauge located on the Bournemouth Pier. The tidal range between MHWS and MLWS at Bournemouth is 1.76 m. The tidal signal at Boscombe is asymmetrical in nature with a prolonged double-peak high water period and a short sharp change in water levels at low tide (Figure 1b). This asymmetric tidal curve means that water levels are above mid tide level for 75% of the time and had significant impact on the reef design. To ensure that waves break on the reef for a reasonable proportion of the tidal cycle it was necessary to raise the crest to a level above mean low water springs.

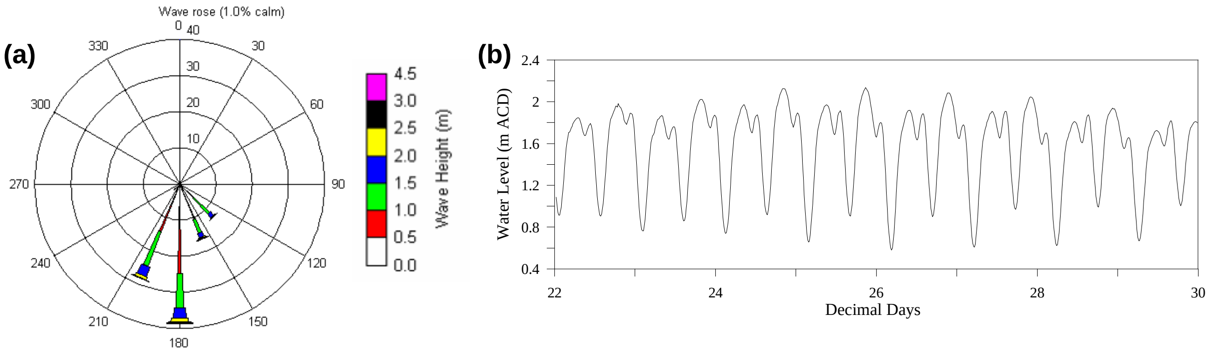


Figure 3.12 (a) A rose plot for the Boscombe wave climate showing waves coming from predominantly a southerly and south-southeasterly wave direction. (b) A time series of the highly asymmetrical tide signal at the reef site.

Multipurpose Reef Design

The final reef design incorporated the following main features; a dual level reef with a focus section designed to draw maximum wave energy onto the reef and a ridge along the crest to break waves in a manner suitable for surfing. The design has a crest height of 0.9 m above chart datum. The reef produces a predominant right hand surfing ride up to 70 m long with a shorter – 30 m – long left hand break. The white-water generated after breaking on the left-handed wave will damp short-period chop originating from the south west quadrant so that it does not propagate through to the main right-handed wave. This design was set in water depths of 3-5 m (CD) (Figure 2.2 a).

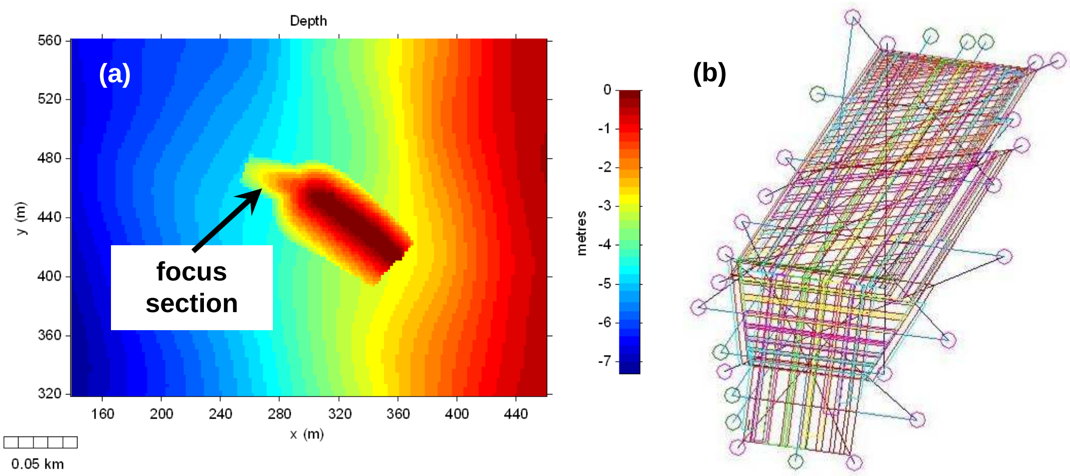


Figure 3.13 (a) Computer generated, numerical model design shape of the Boscombe Multipurpose Reef and (b) a schematic of the geotextile container layout and section anchoring strategy for the full scale prototype (right).

The reef design was further optimised through physical laboratory scale modelling. For theses studies a model of the reef at 1:30 scale was built using scaled construction elements representing the sand filled geotextile containers that would be used to construct the reef in reality. With this method the reef shape could be fine-tuned and the container layout specified prior to construction. Based on qualitative assessments of the wave breaking on the completed reef, the laboratory modelling was reasonably accurate (Figure 3).

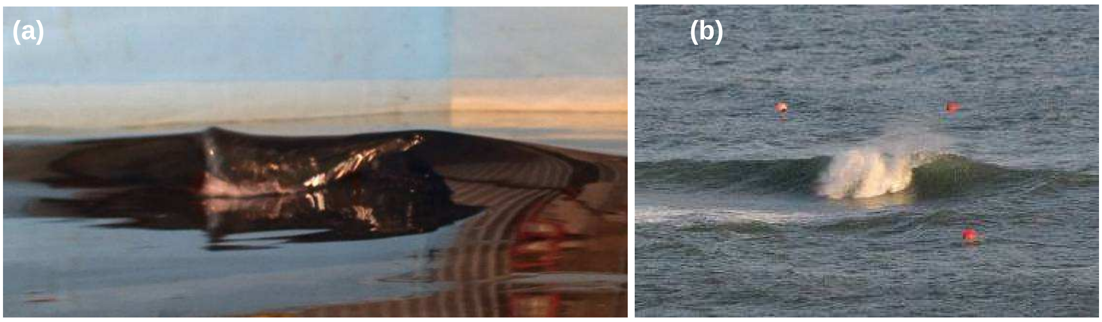


Figure 3.14 (a) Wave breaking over a laboratory model of the Boscombe Reef and (b) a wave breaking over the nearly completed reef.

3.5.3 Reef Construction

Reef construction began in the summer of 2008. Construction was based on using large sand filled geotextile containers arranged in sections. The sections were compromised of up to 14 individual containers ranging in size from 15 to 40 m long with diameters on the order of 1 to 5 m. Each section was deployed from a barge and anchored to the sea bed with 5 tonne concrete blocks. The containers were filled through the use of a land-based pumping system connected to the reef via a 450 m long pipeline. A sand-water slurry was pumped out to the reef and the filling was controlled by divers (Figure 1 a, b).

This methodology was employed for the lower layer of containers, however it was somewhat risky due to the large number of unwieldy containers in each section. If inclement whether set in and containers were left unfilled, there was a risk of containers shifting from their design location. Indeed, weather was a factor during the first construction season and only the first layer of the reef was able to be finished. Once winter set in, construction was suspended until the following summer. During the second construction season in the summer 2009, a single container deployment method was used. Each container was folded on to a floating raft, hitched into position and anchored to the sea bed before filling. This method was effective and efficient and allowed the reef to be completed before the end of the construction window.

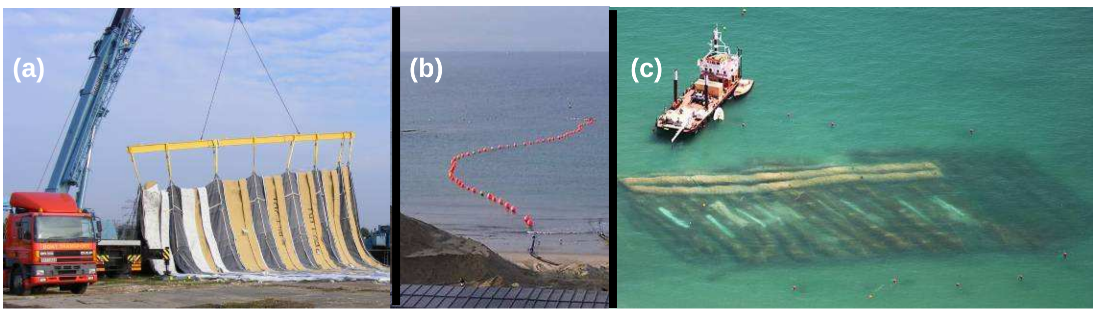
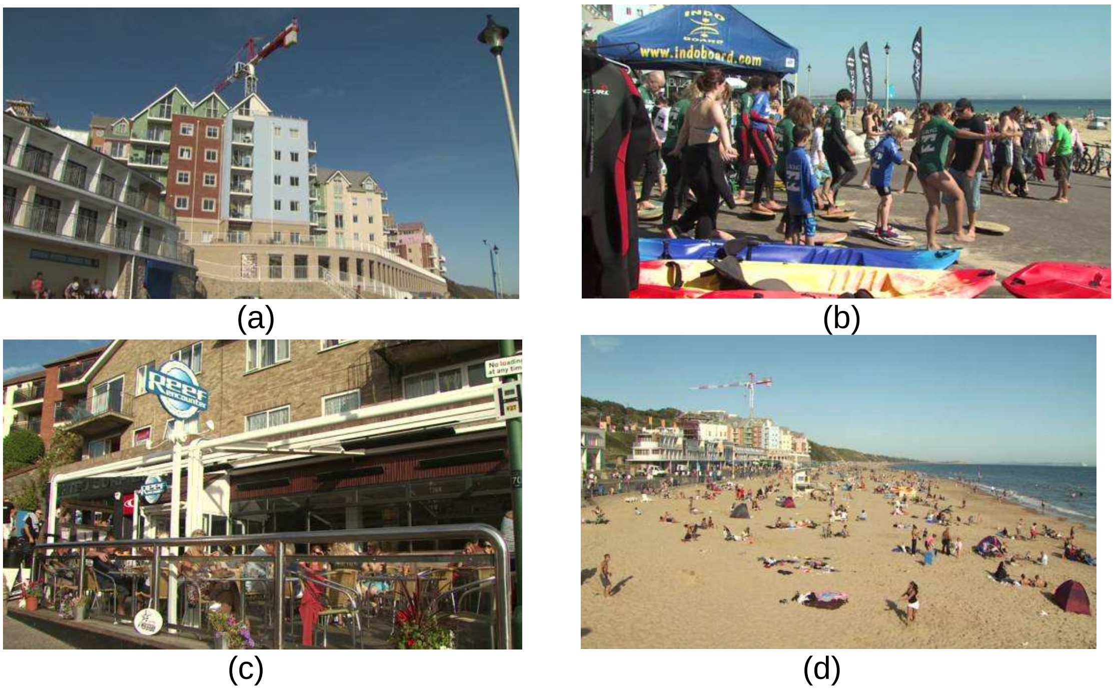


Figure 3.15 (a) Hoisting a section on to the barge for deployment (b) the sand slurry pipeline (c) the completed lower layer with two of the top layer containers in place.

3.5.4 Economic Benefits

The BBC has been working for the past 3 decades on an economic rejuvenation plan for the city of Boscombe. At the heart of this project is Europe's first Multi Purpose Reef. By the time it was officially inaugurated in November 2009, the Reef had already proven itself as a powerful driver of economic activity. The publicity value of Boscombe's economic revitalization plan, of which the reef is a primary component, has already been estimated at approximately 10 millions pounds (source: Bournemouth Borough Council). The reef itself has been the catalyst for economic investment along the beach front, specifically:

- Reef themed restaurants with sea views overlooking the reef site,
- the creation of surf schools and
- residential development projects.



(a) (b) (c) (d)

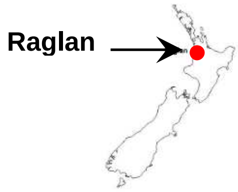
Figure 3.16 (a) Residential development . (b) Creation of surf schools. (c) new bars and restaurants. (d) attracting the crowd.

Figure 3.17 Aerial picture of the Multi Purpose Reef in Boscombe (UK)

3.5.5 Amenity enhancement

Since completion in the late summer of 2009, the reef has provided numerous wave riding opportunities for local surfers an bodyboarders. As with any new surfing spot, especially a ledgy slab-like reef break, the local riders needed a few sessions before they understood how the wave worked, where to sit and when it worked best. As one of the coldest winters in UK history set in, sessions on the reef have dwindled, however, we anticipate more sessions on the reef as spring returns and the weather warms up. ASR will be returning to Boscombe this summer to complete the finishing touches to ‘Boz’.

Figure 3.18 Results on local surfing conditions (a) 1st of November 2009 (b) and (c) December 2009



4 COMPANY INFORMATION

4.1 ASR Ltd. Background and Capabilities

ASR has a wide range of expertise and experience in multi-disciplinary consulting and research in the aquatic environment (marine and freshwater). ASR was formed to provide a unified “environment” for professionals in marine science, consulting and engineering. Although a relatively young company, ASR boasts one of the largest groups of physical coastal experts in private industry in the Southern Hemisphere. The company has flourished because it has evolved organically, transitioning in to consulting from the academic and research world into a fully independent consulting group, making decades of academic and research experience, as well as project management experience, readily available to clients. Directors and senior staff have PhD’s or extensive experience in coastal processes and oceanography and noteworthy scientific, consultancy and popular article publication lists. When combined, the company‘s Directors and staff provide a capacity that ensures the goals of the present project will be met at the highest possible level.

The company specialises in numerical modelling and coastal field studies of outfalls, fish larvae, waves, beaches, ports and harbours etc, but ASR is particularly well known for its world leadership in multi-purpose reef design and offshore coastal protection. The company provides a niche resource in New Zealand, and internationally, by underpinning less technical groups with high-quality advice and technical skill on coastal, estuarine and freshwater processes. ASR also actively collaborates with other national and international research institutes and universities e.g. CESS (India), MAFRI (Australia), Waikato University (New Zealand) for projects related to coastal and estuarine processes, multi-purpose reefs, coastal zone management, water quality and software development.

Further details on ASR’s expertise, experience, project management structure, projects and personnel can be accessed at www.asrltd.co.nz and are also provided in the Appendices.

4.2 Company Size and Technical skills of Key ASR Personnel

ASR has 22 full-time staff, 3 part-time staff, and normally has 2-6 international interns working in the Raglan offices. In addition, ASR has a wide range of associates that are regularly involved in projects (e.g. Dr. Tim Haggitt (Coastal and Aquatic Systems Ltd), Dr. David Phillips (Dept of Environmental Engineering, UNITEC), Prof. Emile Okal (Northwestern University, Illiois).

ASR have a wide range of equipment available for fieldwork including drop-cameras, Acoustic Current Doppler Profilers (ACDP's - Workhorse *Sentinel ADCP* and SonTek), several simple transportable bathymetry survey systems, FLNTU turbidity sensors (Combination Chlorophyll Fluorometer and Turbidity Sensor) **,** LISST (Laser In-Situ Scattering and Transmissometery) particle analyser, salinity gauges for plume dispersal deployments (FSI and Odyssey), Aquadopp Wave/Current Meters, field GPS units, temperature thermistor strings, video sled for seabed transects (used to over 120 m depths), equipment sleds for data collection in moving water (surfzone and river studies), diving equipment, a 5 x 10 m wave basin and a variety of other sampling devices, mounts, frames and measuring instruments. ASR’s 3DD suite of numerical models are coupled, state-of-the-art, hydrodynamic and sediment transport models that are utilised in a wide range of projects to expand the ‘point-source’ data acquired by instruments to enable understanding of large areas and assess impacts of coastal structures, oil spills, effluent dispersal, etc. Thus, ASR has the capacity to undertake a broad range of projects, and has successfully done so for over a decade.

5 COASTAL PROCESS STUDY

While ASR are known world-wide for their development of multi-purpose reefs for coastal erosion control and enhanced amenity and aesthetics (when compared to land-based hard engineering), ASR is not single-minded in its approach to coastal management and the company is involved with coastal projects that utilise renourishment, detached breakwaters, sand by-passing, submerged reefs, groynes or dune management among other options. Quite often hybrid solutions that incorporate a range of solutions are needed to get the required response for a particular situation. Our approach to any coastal problem/development is to first understand and quantify the existing physical processes operating at the site of interest. Each site is different and has its own specific processes operating, and so, there is no generic solution that can be applied to any beach. ASR run an international computer modelling house – numerical models are the most advanced and powerful tool available to the modern coastal engineer/scientist. The 3DD modelling suite will be used in the present study (Appendix 2).

In the present case, the objective is to develop a quantified understanding of the coastal processes operating in the Wooli Beach area (Figure 5.1). Wooli Beach is some 7 km long between the headlands at Wilson's Head (north) and Jones' Beach (south). Extensive and complex offshore reefs existing at both ends of the bay which influence wave transformation into the beach and sediment transport both along the beach and around the headlands. Human intervention has likely had profound impacts on the beach processes, such as the river training walls that capture sand in the southern embayment (Jones' Beach), reduce sand supply to the beach from the river, and have possibly subtly changed the beach plan shape. The beach is fronted up high dunes (up to 10 m) with foredunes in some areas of the beach, which is mostly a wide platform above the steep intertidal beach, which is over-topped during high tide with large wave events and storms (Figure 5.2). Wooli Beach is classified as an intermediate longshore bar-trough type beach (Wright and Short 1984).

At present, very little site-specific data is available for Wooli Beach (e.g. see WP, 2010a). The following methodology is presented to describe the steps required to collect sufficient data to develop conceptual and numerical models.

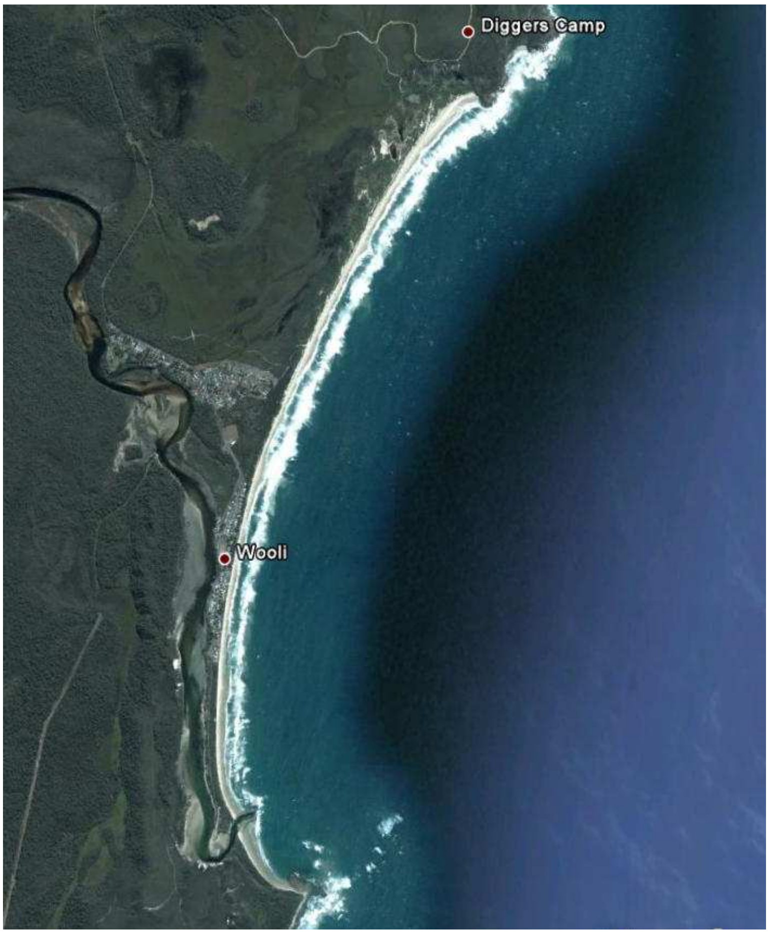


Figure 5.1. Wooli Beach is some 7 km long between the headlands, at Wilson's Head (north) and Jones' Beach (south). Natural offshore reefs have significant impacts on waves and sediment transport, along with human developments (e.g. the river training walls).

Figure 5.2. Wooli Beach – the flat beach platform which is over-topped by waves.

5.1 Objective

In order to develop a Beach Protection Strategy (BPS) for Wooli Beach that addresses the parts of the village currently considered within the 100-year coastal hazard zone (some 800 m), there first needs to be a quantified understanding of the beach processes operating at Wooli. Indeed, to make any decisions on beach management with a good measure of confidence (e.g. development of realistic coastal hazard lines), the existing beach processes at Wooli need to be understood and quantified. Thus, the primary objective of the first study is to:

- Identify and qualify the existing coastal processes at Wooli Beach through data collection and the development of conceptual and numerical models.

5.2 Work Programme

The overall project would incorporate 8 parts:

1. Fieldwork planning/mobilization and lit/data review.
2. Data collection and instrument deployments.
3. Data analysis and correlation of site specific data and long-term datasets to develop tidal constituents and an inshore wave climate.
4. Development of a conceptual model as the basis of numerical models.
5. Development of model grids, boundary conditions and model calibration
6. Hydrodynamic scenario modelling.
7. Sediment transport scenario modelling
8. Reporting and graphics

The final model develops will represent calibrated tools for the application in the next stage of the investigation, i.e. development of a BPS for Wooli Village.

5.2.1 Fieldwork planning/mobilization and lit/data review

Fieldwork planning/mobilization will include:

- Order/purchase of materials for wave/current meters (x3 to be deployed at different locations around the bay, 2 of which will be moved to new spots midway through the data collection), batteries, sediment traps, ropes, buoys, anodes, etc.

- Preparation and testing of wave/current meters, mooring frames, grab-sampler and drop-camera video system.

- Purchase of instrument insurance

A small vessel would be required for deployment, relocation and recovery of instruments

The available information related to the site consists of aerial/satellite photographs, offshore wave and wind hindcast data, hydrographic charts, and some technical reports. A detailed literature/data search will be undertaken to uncover any further useful information.

One of the most important parts of developing numerical models of the coast is good bathymetry data. At this stage it is unknown whether the Wooli area is scheduled for a multi-beam survey (there has been mention of the NSW Government undertaking this for the whole coast). A bathymetry survey of the area using a single beam system has been costed into this study in the meantime,

5.2.2 Data Collection

Upon arrival on site, the following plan will be followed:

1. Deployment of wave/current meters (also records water levels (i.e. tides)) at 3 sites with sediment traps (3 heights) attached.

2. Bathymetry survey of the embayment out to 15-20 m deep

3. Drop-camera video survey.

4. Grab sampling.

5. Beach profile survey

Following the deployment of the wave/current meters, topography and bathymetry survey will be undertaken. Small sediment samples of the beach and seabed material will also be collected for grain size analysis for development of a sediment size map and input into sediment transport modelling.

The instruments will be deployed for 8 weeks, with 2 of the instruments being serviced and moved after 4 weeks. At this stage it is unknown is local wind data is available. These data will be collected using an onsite system (e.g. a windbird) if no data exists – this has not been costed in at this stage

5.2.3 Data Analysis and Development of an Inshore Wave Climate

At this stage, while other data will be briefly assessed, the wave data will be an important focus of the analysis, since wave-driven sediment transport is a large component of morphological change. The wave data will be related corresponding offshore wave data.

Long-term wave data will be extracted from ASR's MDI (Metocean Data Interface). The MDI contains world-wide wave and wind data dating back to 1st January 1997 to present (latest data is downloaded the end of each month). The significant wave heights, peak frequencies and peak directions are extracted at three hourly intervals from the NOAA WW3 wave model hindcast and archived in the system. The WaveWatch3 (WW3) wave model is the world standard, it is a third generation ocean wave propagation model. WW3 solves the spectral action density balance equation for wave number-direction spectra. The model domain is the entire globe between 78°N and 78°S with grid points spaced at 1° latitude and 1.25° longitude.

The wind fields used to drive the NWW3 wave generation come from the NOAA Global Forecast System (GFS), which combines data assimilation and a forecasting model – these data are also uploaded into the ASR MDI every month. The near surface wind field is converted to 10 m wind speed over the NWW3 grid. The NWW3 hindcasts are run with the archived (historical) wind fields. Wind data is also provided in three hourly bins and can be extracted on a grid of regularly spaced points of wind velocity components. These data are from the most reliable source available worldwide, and recent comparisons with measured wavebuoy data has demonstrated that the modeled data is a very good fit to measured (e.g. McComb *et al*., 2002; Mead *et al*., 2005; Borrero *et al.*, 2006). The limitations of the wave hindcast data used for this type of analysis is the tendency for the hindcast data to underestimate the peak wave heights during extreme events, but more importantly the interpolation method utilised for wave directions in shallow water. The latter limitation can be overcome by using refraction modelling to transform the data to the inshore site. Models SWAN and WBEND will be utilized to transform offshore wave data into the site, with the on-site measurements used for calibration of the models.

Water level measurements will be used to develop tidal constituents to predict the long term tidal fluctuations at the site, which will in turn be applied to the model development and used to to assess scenarios during different tidal levels/currents.

Wind data will first be related to long term records and then correlated with coincident wave data.

Sediment samples will be grain sized at the University of Waikato's laboratory using a Malvern laser particle sizer..

Drop-camera video recordings will be hyperlinked to an interactive map of the site to provide a substrate map of the selected area.

5.2.4 Development of Conceptual and Numerical Models

In the first instance, a conceptual model is developed from the range of existing and gathered data. This model provides the blueprint for the development of numerical model components.

The corrected bathymetry data (will be compiled with data collected with hand-held GPS, beach profiling, digitized nautical charts (of Lakes and coast), and aerial photographs to develop modelling grids. A model grid to beyond the continental shelf is required for wave transformation modelling to develop a long-term inshore wave climate for Wooli Beach.

Wave and tidal data will be converted to model boundary files to cover the most common conditions and extreme conditions (i.e. floods and storms).

The field measurements of waves, currents and water levels at the site will be used to calibrate the models so that they reproduce the existing environment. Once this has been achieved scenario modelling of first the hydrodynamic processes (waves, tides and currents) can be undertaken, followed by sediment transport modelling (Figure 5.3).

5.2.5 Reporting and Graphics

A concise report will be created that outlines the methodology applied and the findings and recommendations, supported by graphics. The models developed through this process will then be applicable to the development of a BPS for Wooli Beach.

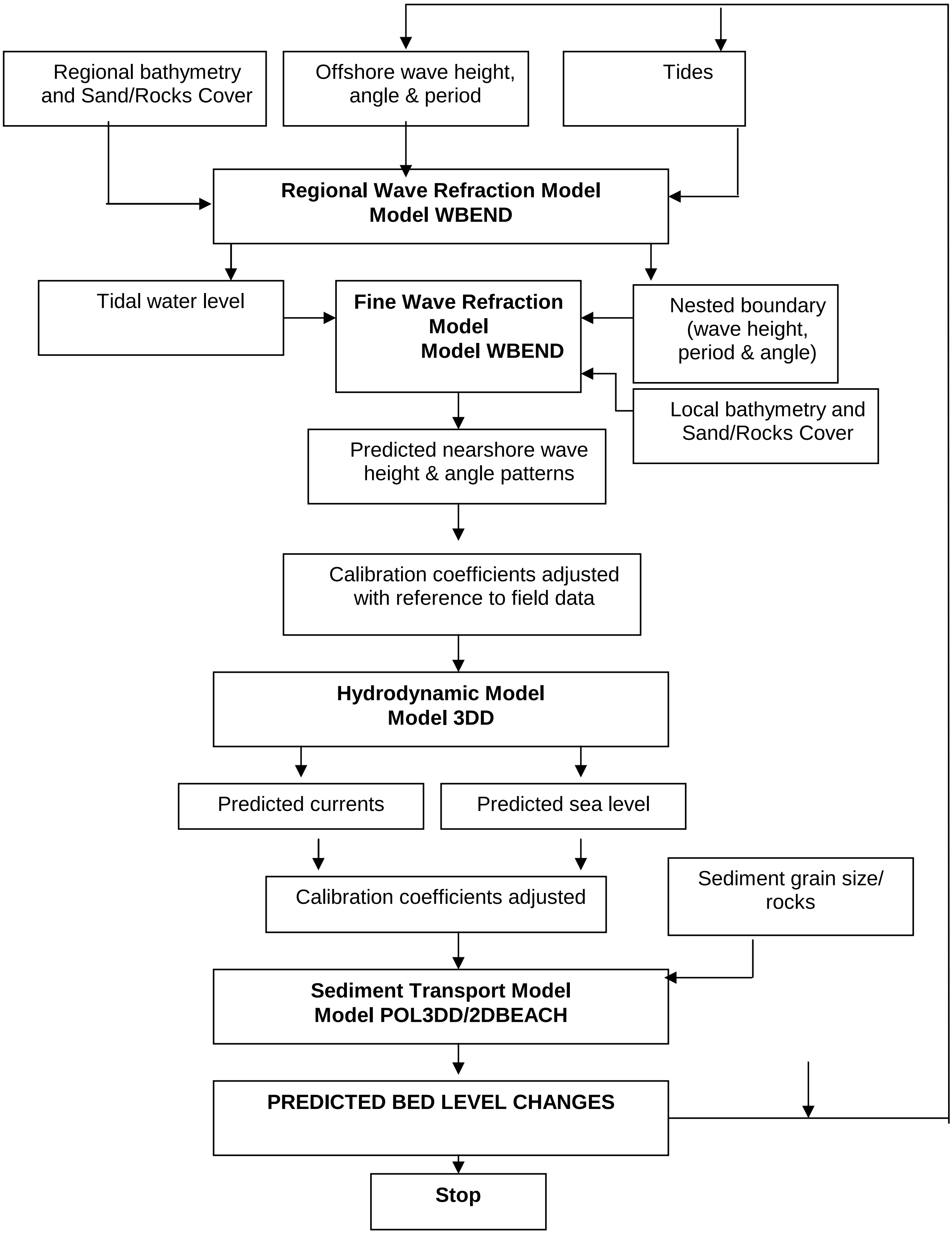


Figure 5.3. Sediment transport modelling flow chart

6 COST AND TIME ESTIMATES

5-6 months would be required to undertake the study described above.

The cost estimate for the full study would include:

Task	Time	Cost (AUD)
Instrument Rental	56 days @ $75/day x3	12600
Mob/dem	3 day technician	3000
Time in the field	10 day tech/sci	12800
Consumables	Batteries, ropes, etc	3450
Travel/Freight		5400
		37250
Data Analysis-Lit Search	Mod/Sci 8 days	10880
Development of inshore wave climate	Modeller 4 days	4960
Development of Conceptual Model	Tech 1 days, Sci 3 days	5500
Design grids and calibration	Sci 5 days, Modeller 10 days	20200
Hydrodynamic scenario modelling	Sci/Mod 5 days	8000
Sediment transport scenario modelling	Sci/Mod 15 days	20200
Reporting and Graphics	Sci/mod 5 days, Tech 3 days	10800
		80540
Total		117790

Notes: 1. Costs of small vessel, accommodation, instrument insurance, and GST are not included.

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Wright and Short, 1984

7 APPENDIX 1 – SURFING SCIENCE

8 APPENDIX 2– 3DD MODELLING SUITE

The numerical model suite **3DD** consists of a full set of marine and freshwater simulations of all physical processes relevant to planning, management and research of our environment (www.asrltd.co.nz). The suite is fully matured, developed over a broad series of science programmes and is now available for commercial and research use worldwide in Windows.

The current technology in **ASR's Numerical Models** arose from focused studies, such as the "Wave and Sediment Dynamics" research funded by the Australian Research Council. The main success of the models, however, stems from years of practical application in every possible marine and freshwater environment, from rivers and lakes to beaches and seas. The applications range from biological to oil spill planning, port dredging and beach erosion and protection.

Experience in coastal research, driven by the conviction of coastal scientists to see better solutions to coastal problems, has meant that the **3DD** suite has become the primary tool for understanding, predicting and managing the environment, during many projects.

Modern, sophisticated computer models of oceans and bays can provide close predictions of waves, currents and sediment movement. When adequately confirmed by field data, these models provide an understanding of physical processes unparalleled by other methods of investigation.

ASR has highly experienced staff capable of undertaking the full range of tasks using models, and takes pride in its world position as an "international modelling house". The numerical models of the 3DD suite are leased or used in research projects around the world.

The models from the **3DD** suite are:

3DD©	3-dimensional flows, dispersal, short-wave and ocean/atmos. heat transfer
POL3DD©	3-dimensional dispersal
WGEN©	Estuary wave climate
WBEND©	Refraction of monochromatic and spectral waves
2DBEACH©	Beach circulation and sediment transport.
GENIUS©	Sedimentation around coastal structures.

Model 3DD©

The 3-dimensional hydrodynamic model **3DD** (developed in Windows by Dr. Kerry Black) has been used successfully in numerous studies around the world and in New Zealand.

The model is a primary component of the ASR hydrodynamic modelling system, which provides accurate and comprehensive simulations of a complete range of processes, over time scales of seconds to weeks. Based around highly accurate mixed Eulerian/Lagrangian mathematical techniques, the model **3DD** provides state-of-the-art- hydrodynamic and dispersal simulations. Developed and sustained by comprehensive field measurements and supplementary modelling packages, the **3DD** suite has been validated to achieve an unprecedented level of numerical refinement. High-quality animated graphics allow the model outputs to be easily interpreted by non scientific people.

3DD is essentially five different models coupled into one fully-linked computer code dealing with:

- Side-view, 2-dimensional, 3-dimensional homogeneous and 3-dimensional stratified hydrodynamics
- Lagrangian and Eulerian dispersal models, including buoyant plumes
- Ocean/Atmosphere heat transfers
- "Boussinesq" short waves
- Radiation-stress wave-driven circulation

With continuity of style maintained throughout the model suite and the support software, **3DD** can be operated in 2 or 3 dimensions using the same input files, thereby ensuring an effortless transition. **3DD** is fully coupled with dispersal, sediment transport, oil spill and wave refraction and wave generation models so that model-generated information can be transferred within the suite to enable the world's most complex environments to be accurately simulated.

The model's enhanced features include:

- Windows-based operation graphics to the screen at run-time as a diagnostic aid
- optional "batch mode" operation for multiple unattended simulations
- easy data entry
- third-order accurate derivative approximations to the advective momentum terms to eliminate grid-scale zigzagging
- a boundary slip parameter which eliminates the problem of excessive damping of currents in narrow channels due to horizontal diffusion
- inter-tidal flooding and drying schemes which prevent development of velocity spikes on the sand banks, and no smoothing of bathymetry is required
- an "effective depth" formulation which prevents excessive frictional resistance in very shallow water

- a body force procedure to simulate large-scale pressure gradients associated with coastal trapped waves, other continental shelf waves or geostrophic gradients when sea level boundary data are unavailable
- a variety of vertical eddy viscosity formulations
- multiple station weather and environmental time series inputs full heat transfer formulations and time series inputs
- hot starts nested simulations
- "double" bathymetry resolution without increasing CPU requirements
- baroclinic side-view simulations for rapid speed

Model POL3DD©

The dispersal model **POL3DD** (POLlution dispersal coupled to 3DD) tracks suspended "particles" to simulate water-borne dispersal including larval behaviours, oil spills, outfall and estuarine or beach sediment transport. The sediment model uses Lagrangian techniques which are particularly useful near sharp concentration gradients, as they exhibit minimal numerical diffusion/dispersion because the particle positions are exactly known and particle advection is calculated directly from the currents.

Transport of effluent, pollutants, salinity and temperature

- concentrations of tracers from multiple sources in 3-dimensions
- vertical and horizontal salinity gradients

Buoyant plumes and oil spills

- buoyant plumes using a novel layered technique simulating surface, multiple sub-surface and bottom layers
- surface transport and beachings of oil spills or other floating contaminants

Sediment dynamics

- bedload and suspended load sediment transport
- sediment erosion/deposition
- full grain size distribution

Decay

- time-varying bacterial inactivation
- selected mass transformation processes

Larval transport

- larval dispersal
- active behaviour

POL3DD is linked to a 3-dimensional hydrodynamic model (Model **3DD**) so that detailed flow patterns can be directly utilised. In addition, **POL3DD** can be simultaneously coupled to a wave generation model (**WGEN3DD**) or the wave refraction model (**WBEND**) so that bed entrainment by wave orbital motion, wave current/interaction and vertical mixing due to waves can be treated over the model grid.

Model WGEN©

The wave generation model **WGEN** (Wave GENeration coupled to 3DD) was developed for fetch-limited water bodies and treats plan shapes which change during the tidal cycle with the submergence and emergence of intertidal sand banks. **WGEN** applies the JONSWAP (JOint North Sea WAve Project) equations assuming pseudo-steadiness and is therefore most useful in small estuaries of up to about 40 km maximum fetch. Since the original version presented in 1992, the model has been extended to include depth-limited breaking, shoaling and bed friction in the JONSWAP formulae. WGEN has been linked to the hydrodynamic model 3DD so that nonlinear wave-current interactions in the bed friction term can be treated, while coupling with a sediment dynamics model provides for calculation of sediment transport in wave and current environments.

Model WBEND©

Model WBEND is a 2-dimensional numerical wave refraction model for monochromatic waves or a wave spectrum over variable topography for refraction and shoreline longshore sediment transport studies. The model applies a fast, iterative, finite-difference solution of the wave action equations to solve for wave height, wave period, breakpoint location, longshore sediment transport, bottom orbital currents and near-bed reference concentration of suspended sediments. WBEND has unique characteristics such as:

- an enhanced shoaling facility to overcome under-prediction of breakpoint wave height which is common to all other linear wave models
- proven capacity to simulate the difficult cases of surfing reef wave transformation, breakpoint peel angle and breakpoint height
- a pseudo-diffraction algorithm simulating diffusion of height and angle along the wave crests
- multiple bed friction choices
- prediction of bedform geometry in response to prevailing wave conditions, and feed-back into the bed friction term
- coupling to the hydrodynamic model 3DD and sediment model POL3DD for simulation of wave-driven circulation and sediment transport in wave and current environments

Model 2DBeach©

Model **2DBeach** is a unique beach circulation and sediment transport model that uses a mixed Lagrangian and Eulerian solution scheme to obtain highly-accurate simulations over complex natural bathymetries. The height transformation method, plus **2DBeach**'s many features and simple operation, sets this model apart, and makes it one of the most appealing general-purpose beach models presently available. In one fully coupled computer code, **2DBeach** contains:

- A Lagrangian wave height transformation model treating conditions beyond, through and inside the breakpoint
- A non-linear, wave-driven hydrodynamic model,
- A wave angle transformation simulation using a rapid iterative solution and
- A wave and current sediment transport model able to treat multiple grain sizes, "real-time" seabed adjustments and enhanced suspension around the breakpoint under plunging waves

2Dbeach has unprecedented capacity to predict features such as rip currents, sand bar movement, beach transformations, storm erosion and the build-up of beaches after storms. In **2DBeach**, the unsteady wave height transformation equations are solved using a combination of Lagrangian and Eulerian methods which eliminates the numerical diffusion errors that are common to purely Eulerian solutions. The Lagrangian scheme also effectively handles the sharp discontinuity in wave heights across the breakpoint. A non-steady, non-linear hydrodynamic model is linked to the wave transformation models through radiation stress terms in the momentum balance equations. The sediment transport model uses a vertically-averaged form of the suspended sediment concentration equations to treat spatial variation in suspended sediment concentration and differential settlement and the consequential seabed "real-time" adjustments

Model Genius©

Model **GENIUS** predicts refraction, breakpoint wave conditions and longshore sediment transport on beaches. **GENIUS** is similar to its well-known counterpart GENESIS (Hanson and Kraus, 1989) but with some extra features including frictional attenuation of wave height and a more physically-based treatment of wave transmission factors across submerged reefs.

In **GENIUS**, the results are obtained by assuming that the longshore variability in bathymetry is small so that Snell's Law is applicable. When this assumption is not acceptable, wave transformation predictions should be made using the more complex model **WBEND**. **GENIUS** accepts a time series of wave conditions to find net longshore sediment fluxes. Offshore wave heights are transformed into shallow water using linear wave relationships to find the refraction and shoaling coefficients. Frictional attenuation is applied by approximating the methods adopted by **WBEND**. Breakpoint height and angle are obtained by iterating the linear wave refraction and shoaling relationships. Longshore sediment transport is calculated using the CERC formula applied in GENESIS.

Plot3DD graphics©

Plot3DD is a Windows-based high quality graphical support routine written in Matlab for the 3DD suite. The software has been developed over more than 10 years by Dr Richard Gorman (formerly of the University of Waikato and now at NIWA, NZ). With its ability to treat all of the models in the 3DD suite, the user only needs to learn one package to produce high quality graphics. The package provides for pseudo-colour, vectors, 3-dimensinal projections, time series and movies. In addition to the many Matlab options, the 3DD suite of models has been linked with GIS software (ArcInfo) and the AutoCAD drawing packages. In total, a very broad range of graphical outputs are available for all users.

9 APPENDIX 3– ASR PROJECT EXPERIENCE

A Selection of ASR Coastal Processes and Protection Projects

Project	Commencement date	Client	Works Undertaken
IRE Sand Mining Project, Southern India	***May 1999***	***CESS, India***	***Instrument deployments followed by wave transformation and sediment transport modelling to ascertain impacts of sand mining on the coast.***
Takapuna Boat Ramp/Surf Reef Feasibility Study	***Completed 1999***	North Shore City Council	Wave transformation modeling to ascertain the impacts of constructing a breakwater on the existing coast and surfing break
Narrowneck Reef: Erosion Control and Surfing Enhancement	***Oct 1999 (construction)***	***Gold Coast City Council***	***Field investigations, wave transformation modelling, sediment transport modelling and reef design for a submerged reef to protect the coast and provide a high-quality surfing break***
Noosa, Australia Beach Erosion Solutions	Stage I August, 1999 - Stage II April 2002	***Noosa Shire Council***	***Field investigations, wave transformation modelling, sediment transport modelling and reef design for a submerged reef to protect the coast and provide a high-quality surfing breaks***
New Plymouth Foreshore Redevelopment	May, 1999	***New Plymouth District Council***	***Field investigations, wave transformation modelling and preliminary reef design for a submerged reef to provide a beach and a high-quality surfing break***
Mount Maunganui Surfing Reef	***February 1999***	Tauranga District Council	Field investigations, wave transformation modelling, sediment transport modelling and reef design for a submerged reef to protect the coast, provide habitat for marine organisms and provide a high-quality surfing breaks
Wave and Sediment Dynamics on Beaches	August, 1999	NIWA	A large multi-facetted project that included field investigations, wave transformation modeling and sediment transport modelling
Bournemouth Surfing Reefs Feasibility Study	***February, 2000***	MAFF, England	Field investigations, wave transformation modelling, sediment transport modelling and reef design for a submerged reef to protect the coast, provide habitat for marine organisms and provide a high-quality surfing breaks
Opunake Surfing Reef Feasibility Study	***Stage I September***	South Taranaki	Field investigations, wave transformation modelling, sediment transport

Project	Commencement date	Client	Works Undertaken
	2000 – Stage II July 2003	District Council	modelling and reef design for a submerged reef to provide a high-quality surfing break and habitat for marine organisms
Lyall Bay Surfing Reef Feasibility Study	*Stage I October 2000 – Stage II October 2002*	Lyall Bay Reef Charifable Trust	Field investigations, wave transformation modelling, sediment transport modelling and reef design for a submerged reef to provide a high-quality surfing break and protect the coast
Newquay Surfing Reef Feasibility Study	*July 2001*	Newquay Artificial Reef Forum	Wave transformation modelling, sediment transport modelling and preliminary reef design for a submerged reef to provide a high-quality surfing break
Westshore Coastal Processes and Erosion Control Investigation	*May 2001*	Napier City Council	Field investigations, wave transformation modeling and sediment transport modelling to assess the coastal processes and preliminary reef design for a submerged reef to protect the coast
Port Gisborne Expansion	*September 2001*	Port Gisborne	Field investigations, wave transformation modelling, sediment transport modelling and Port wall design to incorporate Port protection, a high-quality surfing break and habitat for marine organisms
Port Dredge Spoil Disposal	*August, 2003*	*Westgate Transport, Taranaki*	*Wave transformation modelling and preliminary dredge mound design to ensure no negative impacts to the coast*
Oil Piers Sand Retention: Ventura, California	March 2003	*The US Army Corp of Engineers*	*Field investigations, wave transformation modelling, sediment transport modelling and reef design for a submerged reef to protect the coast and provide a high-quality surfing break*
Geraldton Surfing Reef Feasibility Study	July 2003	*BBIG*	*Field investigations, wave transformation modelling, sediment transport modelling and preliminary reef design for a submerged reef provide a high-quality surfing break*
Borth Multi-Purpose Reef	February 2003	*Ceregidion*	*Wave transformation modelling, sediment transport modelling and Preliminary reef design for a submerged reef to protect the coast and provide a high-quality surfing break*
Orewa Beach Multi-Purpose Reef	*October 2003*	OBRCT and Rodney District Council	*Field investigations, wave transformation modelling, sediment transport modelling and preliminary reef design for a submerged reef to protect the coast, provide a high-quality surfing break and habitat for marine organisms*

Project	Commencement date	Client	Works Undertaken
Opunake Surfing Reef	*December 2004*	South Taranaki District Council	*Studies for Resource Consent application for the Opunake Surfing Reef, Taranaki, New Zealand. Detailed design, physical and biological impact studies and hearing evidence needed to obtain Resource Consents.*
Palm Beach Coastal Protection Options	*May 2004*	SOS Incorporated	*A review of the design and impact assessment for 3 submerged reefs proposed for Palm Beach in Australia*
Nanuku Surfing Reef Feasibility Study	*June 2004*	Hatherly Dunedin	*Feasibility study for a surfing reef at Nanuku Island, Fiji, for tourism development*
Boscombe Surfing Reef	*August 2004*	Bournemouth Borough Council	*Boscombe surfing reef detailed design - field data collection, numerical modelling and initial design reporting.*
Sandbanks Coastal Protection Options	*January 2005*	H R Wallingford	*Desk study of alternative coastal defence options at Sandbanks, Poole, England*
Cape Otway	*February 2005*	Woodside Energy	*Assessment of the nearshore wave conditions at Cape Otway in Victoria, Australia for the emergence point of a subsea pipeline. Detailed study with numerical and physical modelling*
Urenui Beach Protction	*March 2005*	New Plymouth City Council	*A review of coastal management and an assessment of options for Urenui Beach and first order determination of the coastal processes*
Oakura Beach Erosion Control	*May 2005*	New Plymouth City Council	*An investigation of the shoreline erosion along the western beach of Oakura and recommendations for mitigation*
Ohau and Oteranga Bay Investigations	*June 2005*	Meridian Energy	*Physical process investigation and breakwater design for Oteranga Bay and Ohau Bay, Wellington, for construction of Makara wind farm construction. Numerical modelling, wave Climate Hindcasting and physical impact assessment*
Mount Maunganui Reef	*July 2005*	Mount Reef Trust	*Physical modelling to amalgamate construction materials and methods with detailed design and construction management*
Incorporation of Multi-Purpose Beach Control Structures into the Barcelona Beach Development (Spain)	*August 2005*	Associació Catalana de Surf	*Preliminary design options for multi-purpose reefs to provide coastal protection and surfing amenity as part of the Barcelona Beach Development Plan.*

Project	Commencement date	Client	Works Undertaken
Bay View Coastal Hazard Zoning and Beach Nourishment Plan (New Zealand)	***September 2005***	Fore World Development Ltd	***Review of coastal hazard zones and development of a beach nourishment plan for Bay View Beach.***
Long Branch Surfing Reef (USA)	***November 2005***	SEA	***Wave transformation modelling, sediment transport modelling and detailed design of a sand-filled geotextile container multi-purpose submerged reef and beach amenities to provide a high-quality surfing break and sand retention.***
Cape St Francis Beach Rehabilitation (South Africa)	***January 2006***	SFBBT	***Field investigations, wave transformation modelling, sediment transport modelling and preliminary design of multi-purpose submerged reefs and beach amenities to retain a wide sandy beach and allow for the removal of rock revetments, while providing high-quality surfing breaks and tourism enhancement.***
Pollok Beach and Wells Estate (South Africa), Multi-Purpose Surfing Reefs	***May 2006***	AfriCoast Engineers	***Field investigations, wave transformation modelling, sediment transport modelling and preliminary design of sand-filled geotextile container multi-purpose submerged reefs and beach amenities to retain a wide sandy beach and allow for the removal of rock revetments, while providing high-quality surfing breaks and tourism enhancement.***
Boscombe Surfing Reef (United Kingdom)	***June2006***	Bournemouth Borough Council	***Boscombe surfing reef detailed design – physical modelling and construction management. Construction summer 2007***
Hydrodynamics and Sediment Transport for the Southern Pipeline	***March 2006***	URS/Tauranga District Council	***Field data collection and numerical modelling to assess the impacts of various submarine and bridge-pile pipeline routes on the inner Tauranga Harbour***
Port Phillip Bay and Western Port Water Quality Receiving Model	***February 2006***	Environmental Protection Agency, Victoria, Australia	***Development of a 3-D circulation model to simulate hydrodynamic behaviour of Port Phillip Bay and Western Port and associated estuarine, ocean and catchment (model) boundaries. In addition, the capability to model the water quality constituents of TN, TP, TSS, salt (EC), zinc, lead , pathogens (E.coli, enterococci), Chl-a, and gross pollutants (litter), as well as sediment transport and coastal erosion and deposition due to tidal currents and wave action. Output include in-house use for the EPA with associated training and documentation.***
Los Rosadas Beach Access and Amenity Enhancement	***January 2007***	Costa Chamela Corp, Mexico	***The project involves undertaking the feasibility and preliminary design studies for a sand-filled geotextile container multi-purpose structure to provide sheltered boat launching and surfing amenity at Las Rosada, Mexico. Field work***

Project	Commencement date	Client	Works Undertaken
			(bathymetry survey, instrument deployment and diver surveys) and numerical modelling.
Preliminary Assessment of the Feasibility of Providing a New Entrance to Matakana Island	*February 2007*	Pritchard Group	*Pritchard Group commissioned ASR Ltd to undertaken an assessment to confirm the feasibility of providing a new entrance to Matakana Island. This included reviewing existing information (modelling), site visit and bathymetry survey.*
Detailed Design for Beach Enhancement at 4 Port Elizabeth Beaches	*March 2007*	Nelson Mandela Bay Municipality, South Africa	*Numerical and physical modelling for the detailed design of 4 projects in Port Elizabeth. Projects range from retaining sand on the beach to safe-swimming areas and surfing break development. Design layouts and construction plans and costings are also included.*
Receiving water quality modeling scenarios of Port Phillip Bay and Western Port for the Water Quality Improvement Plan	*April 2007*	Melbourne Water	*Conduct and complete modelling scenarios from the developed receiving water quality model for the Port Phillip Bay and Western Port Water Quality Improvement Plan (WQIP) that integrate with catchment model scenarios outputs, and inform the offsets project (including field data collection).*
**North End Beach Development*	*May 2007*	Africoast Engineers	*North End currently has no sandy beach, just rock revetment due to the presence of the Port blocking littoral sand transport. This project considers the feasibility of developing a sandy beach at North End through field investigations and numerical modelling.*
Dispersion Modelling of Hypersaline Water in Port Phillip Bay and Western Port	*May 2007*	GHD	*Scenario modelling of hypersaline water dispersion from various locations in Port Phillip Bay and Western Port using ASR's existing calibrated hydrodynamic models*
Likuri (Robinson Crusoe) Island Marina Development	*June 2007*	Harrison Grierson	*Field studies (wave/current measurements, bathymetry surveys, grab samples) and numerical modelling to evaluate the environmental impacts and functional performance for a super-yacht marina and swimming lagoons. This project is aimed at ensuring sediment transport is not modified in a way that would have negative impacts on the island, as well as ecological impacts on mangroves and benthic invertebrates.*
Opoturu Bridge/Causeway Assessment	*July 2007*	Maunsell Ltd	*Review of hydrological modelling and expert advice on sedimentation for a proposed bridge/causeway upgrade, including field data collection and modelling for extreme water level analysis to design the height of the bridge soffit*

Project	Commencement date	Client	Works Undertaken
Establishing Numerical models and Collection of Preliminary Field Data for the Proposed Wonthaggi Desalination Plant	***September 2007***	GHD	***Review of existing information, establishing numerical models and collection of preliminary oceanographic data for the Wonthaggi coast and Bass Strait, for environmental impact assessment of Melbourne's proposed desalination plant.***
Orewa Beach Rehabilitation (New Zealand)	***September 2007***	OBRCT and Rodney District Council	***Detailed reef design and Resource Consent Application for sand-filled geotextile container submerged multi-purpose reefs to protect the coast while retaining a wide sandy beach, and providing a high-quality surfing break and habitat for marine organisms***
Mossel Bay Fish Farm – Currents and Dispersal Modelling	***December 2007***	CCA Environmental (PTY) Ltd	***An impact study (including deployment of instruments for data collection) of a proposed fish farm offshore of Mossel Bay, South Africa.***
Raglan Harbour Model	***January 2008***	Research Grant	***Development of a calibrated numerical model for the Raglan Harbour and Bar – field data collection and numerical model development.***
Final Design and Impact Assessments of a New Entrance to Matakana Island	***February 2008***	Pritchard Group	***Final design and impacts assessment (physical and ecological) of a new entrance to Matakana Island. The resort application is currently being processes (Nov 2008).***
Opoturu Bridge/Causeway Numerical Modelling and Ecological Assessment	***May 2008***	Raglan Land Co.	***Development of a numerical model to test impacts due to the removal of the existing causeway and construction of a bridge at Opotoru. Ecological assessment of the rocky substrates at Opotoru and other areas of the Raglan Harbour. Reports to support Resource Consent Application.***
Corniche Bay Beach Development (Mauritius)	***April 2008***	Arup Consultants	***Corniche Bay is a 5-star resort that is to be developed in south western Mauritius. ASR is a part of a large team of consultants, with our particular brief to developing a wide sandy beach for the frontage of the resort, and consideration of additional water-based amenities.***
Development of a Coastal Management Plan for South West India	***July 2008-2010***	Asian Development Bank	***Development of beach management solutions for >40 beaches on the southwest coast of India, including field data collection and detailed design for 4 demonstration sites (MPR's).***
Boscombe Surfing Reef Construction (United Kingdom)	***August 2008 – August 2009***	Bournemouth Borough Council	***Construction of the Boscombe Multi-purpose Reef. The bottom layer of the ~14,000 m^3 reef has been completed. Remobilization is scheduled for next April***

Project	Commencement date	Client	Works Undertaken
			(2009) and completion is expected in autumn 2009.
Sustainable Kelp Harvesting, Waihau Bay, New Zealand	November 2008	CASL/Agrisea	A 5 year project of clearance and monitoring of varying sized patches of Ecklonia radiata, a kelp used for developing high potency fertilizer for agriculture and viticulture.
Western Treatment Plant Outfall Study	December 2008 – September 2009 (in progress)	Melbourne Water	Field data collection and establishment of numerical models for determining the dispersion of POC from the Western Treatment Plant outfalls. This project is being undertaken for the renewal of outfall permits.
La Roche Percee, New Caledonia – Beach Renourishment and Multi-purpose Reef Development	January 2009	CAPSE Nord	Field data collection, numerical modelling and design assessment for beach restoration and coastal protection. Previous failed coastal protection methods have left this turtle nesting area unsuitable for turtles or amenity. Renourishment will be retained by an offshore submerged reef.
Maraetai Beach Coastal Processes and AEE	February 2009	Harrison Grierson Manukau City Council	Bathymetry survey, instrument deployment and numerical modelling of Maraetai Beach, Auckland to assess the coastal processes and likely impact of renourishment for coastal protection.
Uitoe Peninsula Resort Development, New Caledonia	February 2009	CAPSE Nord	Instrument deployment and numerical modelling of tidal currents for the construction of a channel/marina and wave modelling of a breakwater for channel entrance protection.
Whitianga Viral Fate Modelling, New Zealand	March 2009	Thames District Council	Hydrodynamic modelling of viral particles from the Whitianga outfall to determine health issues at swimming beaches and in aquaculture areas.
Re-Imaging the Folkstone Shore, England	August 2009	Strandhouse	Preliminary investigation of a series of options to enhance the coastal amenity while working within the available environmental constraints such as the large tidal range and the small, windy wave climate.
Port Phillip Bay Submerged Reefs, Australia	September 2009	Department of Sustainability and Environment, Victoria	The Victorian Coastal Strategy identifies the development of a strategic plan for the management of coastal protection as a key action items for the DSE to address. This strategic plan is to take into account climate change risks, impacts and determine the relative costs and benefits of any future beach protection management options. As part of this effort, this study investigates the use of detached offshore reefs as a means of coastal protection in Port Phillip Bay.
Borth Reef Detailed Design and Construction Documentation, Wales	October 2009	Royal Haskoning	Undertake numerical and physical modelling and aid in the development of the final design of the Borth multi-purpose reef

Project	Commencement date	Client	Works Undertaken
Extreme Water Level Predictions for Dixon Island, West Australia	November 2009	RPSMetOcean Engineers	Numerical modelling of extreme water levels due to tides, storm surge and extreme wave events for the design of a new ship loading structure.
Re-Imaging the Folkestone Shore, England	February 2010	Trevor Minter OBE DL	Desktop numerical modelling study to consider creating unique and interesting water-based activities to serve as a focal point for the Folkestone beaches.
Whangateau Harbour Flushing Study, New Zealand	March 2010	Omaha Park Limited	Development of a hydrodynamic modelling and expert witness evidence presentation of the flushing capacity of Whangateau Harbour.
Review of the impacts of the Port Motueka Sand-Deflection Groyne	April 2010	Ben Van Dyke	A first level review of the potential effects of a 700 m long by 1.5 m high geotextile groyne/breakwater that was constructed in 1995-96 with the intention to deflect southerly directed sand from the Motueka Spit offshore and maintain a navigable channel to Port Motueka.
Wailagilala Island Beach Development, Fiji	May 2010	Sean Howard	Field data collection and preliminary numerical modelling to create a more user-friendly sandy beachfront along the 300-400 m stretch of beach on the southwestern side of the main island.
Firth of Thames Hydrodynamic Model, New Zealand	May 2010	Environment Waikato	Development of a hydrodynamic model of the Firth of Thames for the assistance with future management options.
GoodEarth Port Development, India	June 2010	Silambimangalam Shipyard Port Development	Development of hydrodynamic models to determine tidal, wind-driven and wave-driven currents at the proposed shipyard and to investigate potential environmental impacts on the Pitchvaram mangrove forest and mitigation methods if required.

10 APPENDIX 4 – GOLD COAST REEF CASE STUDY