

Living Along The Coast: Building Green Defences to Mitigate The Negative Effects of Coastal Erosion in Auckland

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Abstract

Coastal erosion is a global issue that threatens human habitation and development. It has far-reaching impacts on environmental, economic, social aspects. Natural factors and human activities combined with climate change will exacerbate the rate of coastal erosion. Almost all of Auckland's coastlines are vulnerable to coastal erosion. Traditional engineering methods have a variety of adverse effects to the coastal ecosystem. The research aims to explore some resilient strategies and environmentally-friendly interventions with an integrated vision to mitigate coastal erosion in Auckland.

This study is developed on the basis of Ecological Urbanism, case studies which are relevant to this research and environmentally-friendly techniques are reviewed and advantages among those will be used reasonably. Orewa, the research site for this project, is a popular holiday destination but has suffered from coastal erosion for an extended period of time. After analysing the specific site context, adaptive approaches including protection, accommodation and managed retreat will be individually discussed. Finally, protection and accommodation methods will be applied to Orewa according to the innovative concept of compartmentalisation. In the proposal, newly-created natural buffer zones along the coastal edge will effectively reduce coastal hazards such as erosion and create a resilient coastline for the future.

The proposed design can mitigate coastal erosion with no adverse effects to the coastal environment, and also provide social and economic benefits for the Orewa community. The proposal will contribute to building a resilient coastal community in Orewa. The research method can be used as an example in other coastal settlements and similar research on coastal issues.

Authenticity Statement

I confirm that:

- All work included in this thesis represents my own work.
- The contribution of supervisors and others to this work was consistent with the Unitec Code of Supervision.

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Contents

1. Research Proposal	1	5. Design Evolution	73
1.1 Introduction	2	5.1 Adaptive Landscape Strategies	74
1.2 Research Questions	4	5.2 Design Evolution	79
1.3 Aims and Objectives	4		
1.4 Methodology	5	6. Design Evaluation	129
2. Coastal Erosion In Auckland Region	7	7. Reflection	131
2.1 The Causes of Coastal Erosion	9		
2.2 The Effects of Coastal Erosion	13	8. Conclusion	135
2.3 Coastal Erosion in Auckland	17		
2.4 An Overview of Common Responses	18	9. References	141
3. Research Contextualization	23		
3.1 Theoretical Context	24		
3.2 Technical Context	26		
3.3 Case Studies	33		
4. Site Introduction and Analysis	47		
4.1 Site Confirmation	48		
4.2 Site Context	52		
4.3 Site Analysis	59		

1 Research Proposal

Introduction

Research Questions

Aims and Objectives

Methodology

1.1 Introduction



Figure 1. Cliffs at hiwa Spit, pōtiki, New Zealand (Smith, 1976).



Figure 2. Coastal erosion of sea cliffs at Happisburgh, Norfolk UK (Dunn, 2006).



Figure 3. Beach huts were damaged by flood water in Iconic beach, North Wales, UK (Duell, 2014).

Coastal erosion is a natural and ongoing process which is a critical part of the natural character of the dynamic coastal environment, however, it is commonly regarded as a problem when threatening human habitation or development (Auckland Council, 2016) (see Figures 1, 2 and 3). When acceleration of coastal erosion occurs, it will result in the loss of land and cause shorelines to retreat closer to buildings and infrastructure (roads, water, sewage and gas pipes) (Auckland Council, 2016). The coastal environment can be deteriorated by coastal erosion, resulting in far-reaching impacts on environmental, economic, social aspects.

Natural forces, human activities and climate change will contribute to the acceleration of coastal erosion. About a quarter of New Zealand's coastlines are eroding (Lange, 2012), and nearly all of Auckland's coastlines are vulnerable to coastal erosion (ARC, 2006). Traditional engineering methods which have been widely used to date have many side-effects to the coastal environment, creating more problems at the original site or transferring problems to other areas when 'addressing' coastal erosion (Viles & Spencer, 1995). The aim of this research is attempting to explore some resilient strategies and environmentally-friendly interventions with an integrated vision to mitigate coastal erosion in Auckland.

My research focus is on beach erosion in the Auckland Region. Orewa Beach, which has suffered from coastal erosion for a long time, is the site chosen to test my design methods. This study is developed on the basis of Ecological Urbanism which suggests designs should work with nature not work against it. Excellent case studies and environmentally-friendly techniques that are relevant to my project are reviewed in order to achieve the final aim of my research. Design techniques and methods from the case studies are interpreted in the project. After analysing the specific site context, adaptive approaches including protection, accommodation and managed retreat will be individually discussed and selectively applied to this project based on the compartmentalization concept. In the proposal, newly-created natural buffer zones along the coastal edge will effectively reduce coastal hazards such as coastal erosion and create a resilient coastline for the future.

To test this proposition, I use ecological, economic, social criteria for judging whether these designs can achieve the final goals of the project.

1.2 Research Questions

- (1) How can adaptive landscape strategies be used to mitigate coastal erosion in sensitive areas?
- (2) How will these designs influence the resilience of a coastal community?

1.3 Aims and Objectives

Coastal erosion is a global issue that all coastal countries are currently facing. Common engineering responses do not always work for all natural hazards conditions, and they may result in adverse effects on coastal ecosystems. Consequently, this research aims to explore some resilient strategies and environmentally-friendly interventions with an integrated vision to mitigate coastal erosion in Auckland. The results of the research will provide an innovative example for coastal erosion mitigation and coastal resilience enhancement.

The above aim will be accomplished by fulfilling the following research objectives:

- Understand the causes of coastal erosion.
- Refer to and analyse innovative theory, successful case studies and environmentally-friendly techniques that address coastal hazards problems (such as coastal erosion, rising sea levels) used worldwide. Advantages among them will be used reasonably in the research.
- Study and determine the typical characteristics of a resilient coast.

1.4 Methodology

My methodology is comprised of the following intersecting streams of investigation:

- Contextualisation of the project
This includes three parts: theoretical, technical and spatial contexts.
- Case studies
Referring to and analysing successful design projects that address similar issues.
Advantages among them will be adopted reasonably for my research.
- Site selection and analysis
After confirming the specific site selection, fieldwork will be carried out. During the field studies, accurate information about the site will be obtained, including the actual status of the coast, topography, land use, existing vegetation and investigations of the local communities' culture and lifestyles.
- Design investigations
My design process will be based on the three steps outlined above.
- Conclusion

2 Coastal Erosion In Auckland Region

The Causes of Coastal Erosion

The Effects of Coastal Erosion

Coastal Erosion in Auckland

An Overview of Common Responses

Coastal erosion and accretion are natural processes. The dynamic coastal environment experiences fluctuations and occasional extremes like other natural systems (ARC, 2000). For the coast, there are no inherent hazards. The hazards (such as coastal erosion and tsunamis) arise from the interaction of human use like property and infrastructure (ARC, 2000). With extensive urbanisation, coastal settlements are often allowed to sprawl along the coast in order to obtain better sea views. In many cases, buildings and other infrastructure have been constructed close to coastal edges where there originally were natural buffer zones, such as low-lying dunes. Spaces for natural coastal processes are largely squeezed by human modifications, resulting in coastlines becoming increasingly fragile. When there is not enough room left to accommodate change, coastal erosion becomes a problem, which is a significant risk for coastal settlements and adjacent infrastructure.

Coastal erosion occurs on almost every coast around the world, however, it was not fully acknowledged as a global issue until the mid to late 1980's (Boccellari, 2010). At least 70% of sand beaches in the world are recessional (Bird, 1985) and around a quarter of New Zealand's coastline is eroding (Lange, 2012). Almost all of the coastline in Auckland is vulnerable to coastal erosion (ARC, 2006).

This chapter describes the causes and effects of coastal erosion first, then introduces the current status of coastal erosion in the Auckland region, and finally summarises the common responses (engineering-relevant methods) to address this issue and presents the side effects of those measures.

2.1 The causes of coastal erosion

Marchand (2010) defines coastal erosion as “the process of wearing away material from a coastal profile due to an imbalance in the supply and export of material from a certain section” (p. 6). The reasons for coastal erosion can be classified into three main factors: natural forces, the pressures caused by human activities on shore zones and its hinterlands, and the effects of climate change.



Figure 4. Wellington Storm Surge (Alexander Turnbull Library, 1972).



Figure 5. Haumoana, Hawkes Bay (Ministry of Civil Defence & Emergency Management, 2005).

2.1.1 Natural factors

Natural factors, such as waves, wind and currents, can easily move sand in the littoral area and lead to the rapid positional changes in shoreline (Prasetya, n. d.). In coastal environments, the littoral area extends from the high water mark that is rarely inundated to shoreline areas that are permanently submerged (“Littoral zone,” 2016). Wave energy and wave-induced currents are more or less constant erosional forces. During storm conditions, the combination of storm waves and storm currents tend to transfer sand offshore (Pilkey, Neal & Bush, 2009). Storm-caused erosion is significantly repaired by post-storm onshore transportation of sediment and longshore drift (Pilkey, Neal & Bush, 2009). Another factor contributing to erosion rates is the tidal range (Pilkey, Neal & Bush, 2009). On a macro-tidal (>4 m) beach, a storm striking at high tide will commonly result in greater shoreline retreat than the same storm occurring at low tide; while on a micro-tidal beach, the effect from the tidal range is not as significant in determining the erosion rate (Pilkey, Neal & Bush, 2009). Figures 4 and 5 show large storm waves in Wellington and Haumoana at different times, causing severe coastal erosion.

2.1.2 Human-induced Factors

(1) Human engineering activities

Coastal erosion in many areas is worsened by human activities, such as sand mining, removal of vegetation, reclaiming land, damming and developing ports (Prasetya, n. d.).

Sand mining has become a very common activity around the coast since the early days of European settlement for the use of sand in a variety of industries, e.g., constructions and the production of glass, ceramics, fiberglass, mortar, plaster and iron ore (Peart, 2009). The quantity of sand deposited on beach is decreased due to sand mining from beaches and almost every eastern coastline in Auckland has been mined at some stage (Peart, 2009). For example, sand mining in Omaha, which took place on the tip of the sand spit, is regarded as the reason for the community's coastal erosion (Peart, 2009). Compared with natural channel entrances, which have a significant ability to affect nearby sediment transport, artificially dredged channel entrances, constructed for navigation purposes, have a greater potential for affecting adjacent shores (The National Academies Press, 1990).

(2) Destruction of dunes

The destruction of dune systems due to human activities can also worsen coastal erosion, reducing the ability to accumulate sand and rebuild beach after storms (Peart, 2009). With extensive urbanisation in New Zealand, shore dunes have been greatly modified for the construction purpose by flattening land to obtain better sea views.

Figure 6 shows where frontal dunes were bulldozed in Omaha to improve views, removing their natural buffering role in storm conditions. Very few of New Zealand's shores are undeveloped. Pakiri Beach (Figure 7) is one of the few undeveloped beaches on the east coast of the Auckland region, and Mason Bay (Figure 8) (west coast of Stewart Island) is one the largest unmodified dune systems where the dunes back the magnificent 19-kilometer beach (Peart, 2009).



Figure 6. Frontal dunes were bulldozed at Omaha (Peart, 2009, P. 126).



Figure 7. Pakiri Beach, Auckland (Potton, 2009, p. 223).



Figure 8. Mason Bay, New Zealand (Lind, 2012).

2.1.3 Climate Change

Sea-level rise is the most significant impact of global warming on the coast. Over 80 percent of the heat produced by the climate system is absorbed by the oceans, resulting in the expansion of the sea (Peart, 2009). Like any other coastal countries, New Zealand will face the consequences of sea level rise. The Ministry for the Environment (n.d.) predicts that sea level will rise in New Zealand on average by at least 0.8m by 2090 in New Zealand with respect to

the 1980-1999 average, and another prediction of the average sea level rise will be 1.1m by 2100 (Media Solutions Ltd, 2014) (Figure 9). It will be much more common to have extreme weather conditions like storms and heavy rain events in the future, which will increase coastal erosion and flooding. Figure 10 shows severe storm surges on Tamaki Drive in Auckland in 2014.



(Left) Figure 9. A prediction of the mean sea-level rise of 1.1meters by the year 2100 in New Zealand (Media Solutions Ltd, 2014).

(Right) Figure 10. Storm surge on Tamaki Drive, Auckland (Science Media Centre, 2014).

Coastal areas are hugely popular places for people to settle because of its beautiful environment. It is predicted that three-quarters of the world's population will settle in coastal areas by the year 2025 (Media Solutions Ltd, 2014). As for New Zealand currently, many people live on the coast and two-thirds of them live in flood-prone areas (New Zealand Coastal Society, 2016). Seashore zones are at significant risk of damage from coastal hazards. Future rising sea levels have the potential to worsen coastal hazards such as coastal erosion and flooding. The increased frequency of high-wave energy and storm surges combined with a rising sea level will greatly increase coastal erosion (Pilkey, Neal & Bush, 2009).

2.2 The effects of coastal erosion

The coast plays a significant role in people's lives, and it is deeply ingrained in New Zealanders' culture and identities. People love to live near coasts and spend time at the beach during their summer holidays. In New Zealand, the coast provides abundant food sources, sheltered places to live and transportation, as well as provided a pleasurable place to relax and recreate (Peart, 2009). Numerous effects of coastal erosion could be significant, occurring on multiple aspects, like environmental, economic, social aspects.

Environmental Aspects

Coastal ecosystems, such as salt marshes, mangroves, dunes, wetlands, estuaries and bays, providing important habitats for many different types of plants and animals (The Environmental Literacy Council, 2015). They are degraded because of coastal erosion shrinking the areas where these creatures can live. One example is Louisiana's coastal wetlands, which as reported by the U.S. Geological Survey, lose 75 square kilometres per year due to human activities like dredging and draining (Laine, n.d.). Coastal erosion can also put some industrial properties at risk when these sites are damaged by erosion, allowing pollution to leach into the environment (Cairns, 2015).

Economic Aspects

- Loss of land, property and infrastructure

Coastal erosion can cause inestimable loss of land, properties and infrastructure. When erosion occurs, it results in coastal cliffs or shorelines retreating closer to coastal properties and infrastructure (e.g. water, sewage and gas pipes and roads) (Auckland

Council, 2016). People's income may be adversely affected due to the loss of productive rural land. A report, prepared for the Christchurch City Council by engineering firm Tonkin and Taylor, estimates that nearly 6000 properties in Christchurch and Banks Peninsula could be at risk of coastal erosion over the next century (Cairns, 2015).

- Reducing property' values

The value of properties can be significantly reduced if houses suffer from or are at risk of erosion. Property owners may also have trouble to obtaining insurance or mortgages for houses if there is an existing or likely erosion problem (Hartert, n.d.).

- Fisheries and aquaculture industry

New Zealand is a coastal country and there are abundant marine activities (fisheries and aquaculture industry) that contribute to the nation's economy. When coastal wetlands are damaged and the water quality of estuaries is changed by erosion, these marine-related industries may be heavily affected.

- Tourism industry

Aside from the effects mentioned above, another significant issue is the impact on the tourism industry. Tourism has become an important part of New Zealand's economy. The New Zealand's coasts are not only New Zealanders' favourite, but also international visitors fall in love with them. A survey showed that the number of overseas tourists travelling to New Zealand each year increased over 350 percent between 1998 and 2007, with over 800,000 visits per year (Peart, 2009). However, as a result of coastal erosion, communities that rely on tourism could be financially devastated due to the loss of their beaches (Cairns, 2015).



Figure 11. Crowds sunbathing at Lyall Bay in 1929 (Alexander Turnbull Library, 1929).



Figure 12. Horse riding at Pakiri Beach, Auckland (Auckland Tourism, Events and Economic Development Ltd, 2014).

Social Aspects

- Recreational Values

In New Zealand, the coasts provide places for abundant recreational activities (swimming, fishing, sunbathing, boating, diving, camping, horse riding, etc.) (Figures 11, 12, 13 and 14). Coastal erosion can lead to the width reduction or disappearance of beaches, causing significant impacts on recreation.

More than one-third of adult New Zealanders go swimming at least once per year (although not always in the sea) and one-fourth go fishing. The number of recreational boats in New Zealand has more than doubled from an estimated 176,000 in 1981 to around 400,000 in 2007 (Peart, 2009). Aside from the activities mentioned above, another important part of the New Zealand lifestyle is camping that is enjoyed by a broad cross-section of society, from different ages and incomes. As indicated in a survey undertaken in 2006, more than half of New Zealanders are either regular campers or would like to go camping in the future (Peart, 2009).



Figure 13. Campsite at Takapuna Beach, Auckland (Takapuna Beach Holiday Park, n.d.).



Figure 14. Crowds swimming, sunbathing and walking at Mission Bay (Thornton, 2015).

- Increased Unemployment Rate

Losses in aquaculture (mussels, oysters, fish and shrimp ponds) due to erosion can diminish fishery productivity thereby increasing the number of unemployed people.

- Health Effects

Mental health issues like anxiety and depression can result from the loss of property and uncertainty about future's risk (Hartert, n.d.). The well-being of the community can be impacted by the combination of the social effects mentioned above.

2.3 Coastal Erosion in Auckland



Figure 15. Snells Beach (Rutherford, 2014).



Figure 16. Algies Bay (“Mahurangi Matters,” 2014).



Figure 17. Orewa Beach (Grace, 2014).



Figure 18. Eastern Beach (Smith, 2013).



Figure 19. Bucklands Beach (Peter, 2012).

Auckland has around 1.4 million people (around 32% of the total population of New Zealand) and about 3,700 km of coastline (“Auckland,” 2016). The city’s growth will increase the pressure to developed areas more susceptible to natural hazards. Coastal erosion is one of the four most frequent natural hazards in Auckland, and the others are flooding, storm surges and land instability (Auckland Council, 2016).

Nearly all of Auckland’s coastline is vulnerable to coastal erosion (ARC, 2006). As Auckland Council (2011) states, east coast beaches, such as Omaha, Snells Beach (Figure 15), Algies Bay (Figure 16), Orewa Beach (Figure 17), Eastern Beach (Figure 18), most beaches on the Whangaparaoa Peninsula, as well as Howick Beach, Bucklands Beach (Figure 20) and Mellons Bay, are likely to suffer from erosion during storm.

2.4 An Overview of Common Engineering Responses to Coastal Erosion

A range of different techniques have been developed and utilised by civil and structural engineers to prevent coastal erosion in Auckland, such as seawalls, groynes, breakwaters, jetties and re-sanding. These engineering interventions are the most common response to coastal erosion, and indeed, they work to some extent. However, the side-effects of these solutions are becoming increasingly evident. These hard defences can cause immediate adverse effects on the environment, such as loss of scenic qualities, access and natural resilience to storm surges (Hartert, n.d.). They do not deal with the causes of erosion in a fundamental way to prevent further shoreline erosion. Aside from the detrimental effects on environmental systems listed above, the positive effects of engineering methods will gradually disappear over time. These measures may protect coasts for several decades, however, with the acceleration of sea-level rise and increased frequency of storm intensity, they are likely to be progressively ineffective (Bell, Hume & Hicks, 2001). As Shepherd (2009) states, strong natural forces (including tides, currents, wind and waves) always attack the fragile coastline; engineering methods do not seem to work in this situation, for example at Muriwai Beach (Rodney District, west of Auckland) and many other coastal areas in New Zealand (e.g. Raglan, Gisbourne and Taranaki) (Shepherd, 2009).

Hard engineering interventions

- Seawalls, groynes, jetties and breakwaters

Hard engineering interventions for coastal erosion include seawalls (Figure 20), groynes (Figure 21), jetties and breakwaters (Figure 22). Seawalls for example, which are widespread around the world, are built parallel to the shore and are designed to hold or prevent sliding of the soil, while providing protection from wave action (Linham & Nicholls, 2010). The main function of seawalls is to provide a high degree of protection from coastal flooding and erosion. Construction of seawalls has a long history of helping protect humans and their settlements from tides (“Seawall,” 2016). In the 1st century BC, Romans built a seawall made up of pozzolana concrete at Caesarea Maritima, creating an artificial harbour called Sebastos Harbour (“Seawall,” 2016).

- Disadvantages of hard engineering interventions

Although these engineering countermeasures are now widely used, adverse effects caused by them are obvious.

Firstly, the construction costs of hard defences are very expensive and the maintenance costs are likely to increase in response to sea-level rise. Linham and Nicholls (2010) indicate that the average cost of building 1 km of vertical seawall ranges from US\$0.4 to 27.5 million. The range in cost depends on the different site conditions and seawall heights.



Figure 20. Seawall at Narrow Neck Beach, Auckland (Mcluckie, 2014).



Figure 21. Groynes at Swanage Bay (Mike, 2001).



Figure 22. Detached breakwaters at Maumee Bay State Park, USA (Winters, 1992).

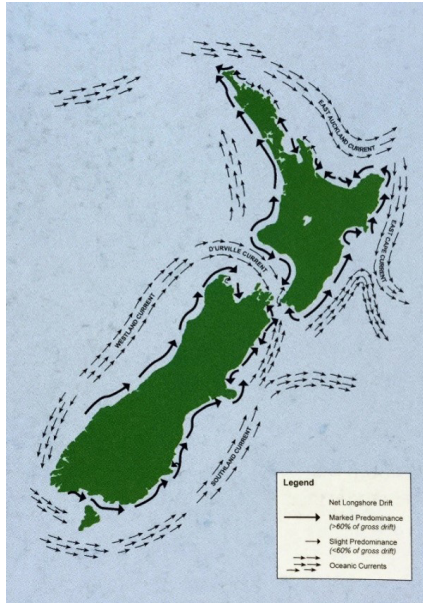
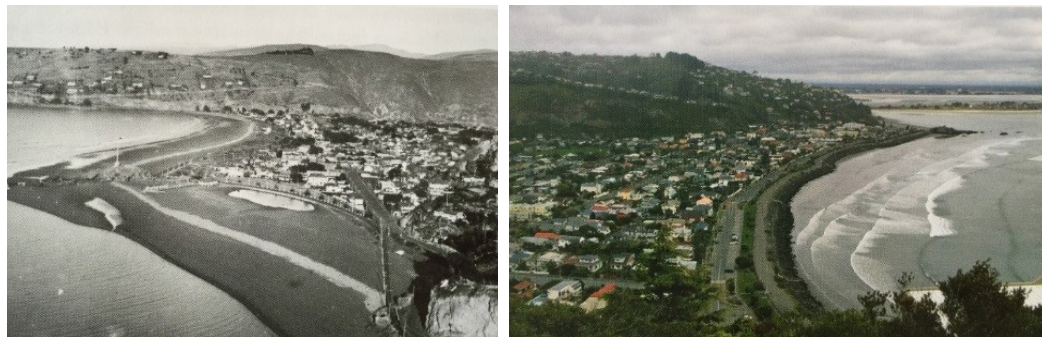


Figure 23. Longshore drift in New Zealand (Peart, 2009, p.18).

Secondly, after utilising these engineering defences, natural coastal systems are altered and their abilities to cope with changing environmental conditions (sediment supply, storms, sea-level change) is reduced. They also lead to the loss of coastal habitat and a reduction in biodiversity (Beachapedia, 2015). Wave reflection from seawalls worsens the loss of sediment from beaches (Beachapedia, 2015). Besides, longshore drift can be disrupted by hard structures (seawalls, groynes, jetties and breakwaters) and erosion usually happens downdrift of seawalls as well (Viles & Spencer, 1995). Longshore drift (Figure 23) is an important process by which sediment is moved along the coast by waves and currents in a predominantly northerly direction (Peart, 2009). While the hard defences address one area's erosion problem they often cause another area's erosion issues. This means that these solutions cannot mitigate the negative effects of coastal erosion in a fundamental way but only transfer the problem to another area and create new issues. For example, on the Bayou Laforche headland (Louisiana, USA), construction of a 1.8 km- long seawalls (hard engineering) and beach nourishment (soft engineering) were carried out in order to prevent coastal erosion along this fragile low-lying beach and dunes in 1986 (Viles & Spencer, 1995). However, severe erosion occurred after two hurricanes in 1988, more serious than most of adjacent coastlines that have a natural beach and dunes (Nakashima & Mossa, 1991).



(Left) Figure 24. Sumner around 1930 (Alexander Turnbull Library, n.d.).
 (Right) Figure 25. Sumner more recently (Peart, 2009, P. 173).

Thirdly, many other natural environments, such as salt marshes, estuary intertidal areas and beaches, are lost due to hard engineering interventions, causing negative impacts on ecosystems, recreation and tourism industries (Bell, Hume & Hicks, 2001). For instance, Sumner (Christchurch) (Figures 24 and 25), which had a wide sandy beach and dune system in the past, was greatly damaged by wave reflection from seawalls constructed in 1941 to 1952 (Peart, 2009).

Soft engineering interventions

- Beach Nourishment

One example of a type of soft engineering intervention is beach nourishment. It is a way of using additional sand to raise the elevation and width of beaches and nearby land (Bell, Hume & Hicks, 2001). This technique is well-known and has been extensively used for the benefit of the tourism industry. There are many successful examples of sand renourishment, such as at Mission Bay (Figure 26) in the Waitematā Harbour in Auckland, Tauranga Harbour and Oriental Bay (Figure 27) in the Wellington.

- Disadvantages of beach nourishment

First, the cost is very expensive and this measure will be ineffective over time because sediment must be occasionally replenished. According to the North Harbour News (2008) in Orewa Beach (Figure 28), re-sanding has happened four times from 2007 to 2008 and has cost about \$30,000 each time. Second, it may be hard to find an adequate sand source to build the beaches. Additional, this technology is merely beneficial to a few people and areas, for the reason that special financial and political support will be needed to ensure future maintenance (Bell, Hume & Hicks, 2001).



Figure 26. Mission Bay (2015).



Figure 27. Oriental Bay (Johnson, n.d.).



Figure 28. Beach nourishment at the Orewa Reserve beachfront (North Harbour News, 2008).

3 Research Contextualisation

Theoretical Context

Technical Context

Case Studies

3.1 Theoretical Context

My research is developed under the theory of Ecological Urbanism which is an evolution of Landscape Urbanism, arguing for a more holistic approach to the design and management of cities (“Ecological Urbanism,” 2016).

Currently, we live in cities that face many challenges from rapid urbanization and limited resources. Urban owns the complex interrelations (economic, political, social and cultural), it needs alternative approaches which are equally complex range of opinions and methods to deal with current issues and potential problems in the future (Mostafavi, 2010). Ecological urbanism approaches cities without any one set of instruments and with a worldview that is fluid in scale and disciplinary approach, and design provides a comprehensive key for linking ecologies with urbanism that is harmonious with its environment (Mostafavi & Doherty, 2010). This theory emphasises the importance of human systems as part of the ecology. Schwartz (2010) states that both human and natural systems are important factors in building sustainable cities, it will fail to create sustainable environment if without human connection to the site.



Figure 29. The aftermath of extreme weather events in Plaquemines Parish, Louisiana, USA, 2005 (Mostafavi & Doherty, 2010, p. 11).

Adaptive design is an innovative approach involving building ecological functions into a landscape, so that it is more resilient to climate change and other environmental impacts. Landscapes and their ecosystems are open and self-organising systems, and to some extent, they are characterised by uncertainty and dynamic change (Lister, 2011). Living systems are in part unpredictable because change is built into them. This is the central notion of adaptive design. In most cases, conventional approaches cannot address issues (such as climate change and coastal hazards) we face nowadays because they are situated in such changeable and dynamic systems (Figure 29). One example is about how to deal with floods— from a gradual transition from flood control to flood management. Over a decade before the devastation of Hurricane Katrina, the U.S. Army Corps of Engineers' approach to flood control was perceived as an effective method for preventing natural hazards in the lower Mississippi Basin. Through the constructions of dykes and dams, and removal of coastal wetlands, coupled with intensive settlement of the floodplains, the natural flood-adaptation function of the basin was impaired (Lister, 2011). When the storm occurred in 2005, the devastation was catastrophic not only for the resources and the economy of the region but for the lives of many of its most vulnerable citizens (Lister, 2011). In this example, traditional engineering approaches to living systems do not work. A more flexible and adaptive approach to manage human activities and to design the systems which sustain us are needed (Lister, 2011).

One important characteristic of adaptive design is “safe-to-fail”. Living systems differ in several important ways from mechanical and structural systems, normally by undergoing changes and moving the system from one apparently stable state to another (Lister, 2011). Small-scale and manageable changes are allowed to happen in adaptive design, without causing catastrophic failure.

3.2 Technical Context

3.2.1 Dunes

Sand dunes (Figure 30) are features of coastal environments formed by wave and wind action (“Sand dune stabilization”, 2016), being the interface between land and sea. Natural sand dunes play a crucial role in protecting inland areas from coastal hazards such as erosion and flooding. They act as a buffer zone against high energy storms and wind forces and provide a sediment reservoir to replace eroded foreshore sediments (Waikato Regional Council, n.d.). Dune construction is used as a vital technique for mitigating coastal erosion in this research project.

- Introduction

Sand dunes are made up of eroded sand and ground rock, which come from terrestrial (e.g. glaciers or rivers) and ocean sources (e.g. coral reefs) (Department of Conservation, n. d.). They comprise three parts: the foredune (towards ocean side), the sand plain (top part of the dune) and the back dune (opposite ocean side) (“Sand dune stabilization,” 2016).



Figure 30. Sand dunes at Omaha Beach, Auckland, 2015

- Working Process

It is important to realise that the natural repair of dune systems is a dynamic process. These changes are considered as a healthy and natural part of this ecosystem, and benefit biodiversity maintenance (Department of Conservation, n. d.).

When storms come, waves erode the beach resulting in short-term erosion, leaving a nearly vertical cut in the face of the dune, as shown in Figure 31. The eroded sand is transported offshore, forming shallow bars that can absorb wave energy. Severe dune erosion can occur in just a few hours, however, the process of dune recovery can take years. Figure 32 shows how dunes are repaired. After a storm, the first step in the recovery is when sand is moved back to the shore by gentle wave forces, and then, dry sand is blown further inland and trapped by dune plants to repair the eroded dune (Waikato Regional Council, n.d.).

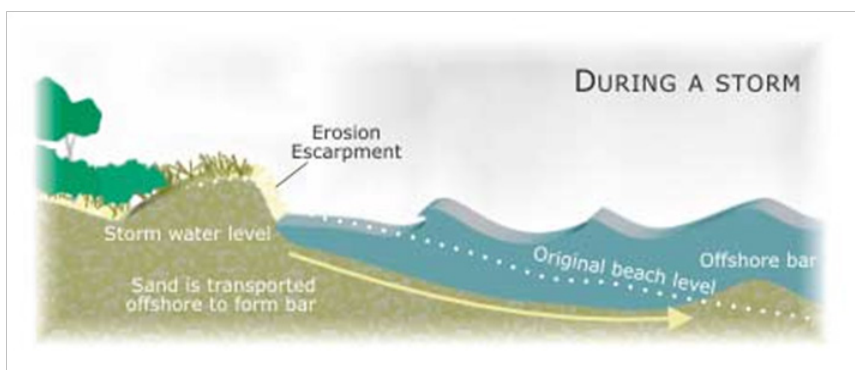


Figure 31. Dunes during a storm (Waikato Regional Council, n.d.).

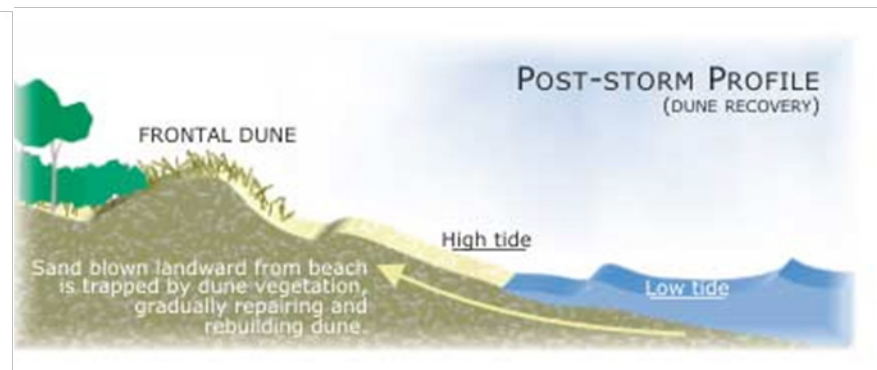


Figure 32. Dunes' recovery after a storm (Waikato Regional Council, n.d.).



Figure 34. Spinifex, Karioitahi Beach, New Zealand (Auckland Council, n.d.).



Figure 35. Pingao, New Zealand (Auckland Council, n.d.).

- Dune Vegetation

A good cover of sand-binding vegetation is vital to the formation and stabilisation of coastal sand dunes. Native dune plants provide the best performance in sand-binding although some introduced plants (e.g. marram) have succeeded in stabilising sand in some areas (Auckland Council, n.d.).

A typical dune vegetation sequence (Figure 33) in Auckland is shown below. Foredune plants such as spinifex (*Spinifex sericeus*) (Figure 34) and pingao (*Ficinia spiralis*) (Figure 35) trap sand and adapt to grow through accumulations of wind-blown sand. Their leaves can reduce wind speed, which allows sand to be deposited (Auckland Council, n.d.). The back dune is more stable and a wide range of plants may grow there (Auckland Council, n.d.).

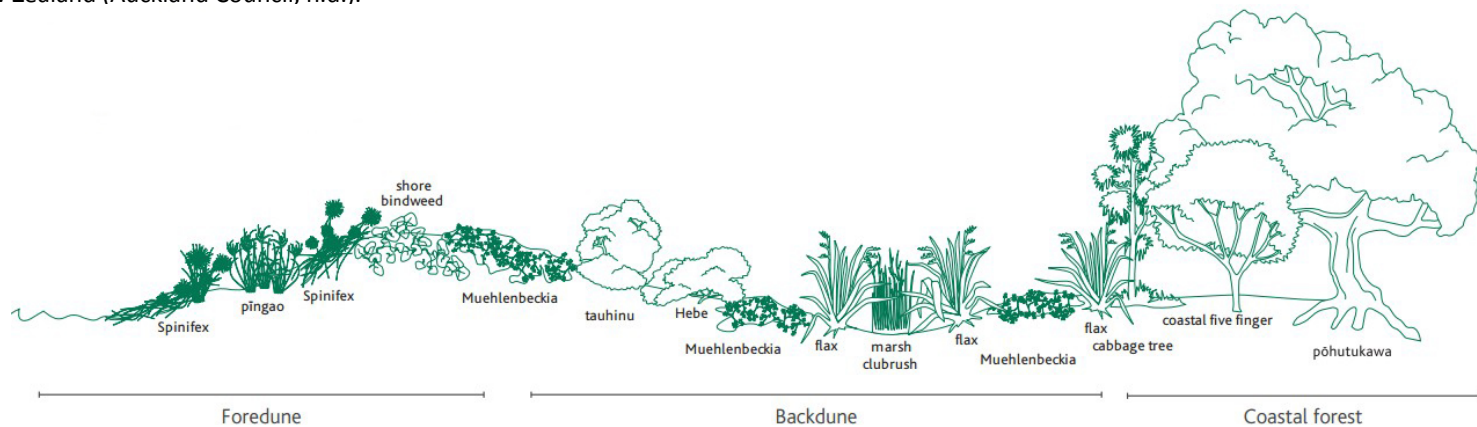


Figure 33. Typical dune vegetation sequence (Auckland Council, n.d.).



Figure 36. Fairy tern, New Zealand (Potton, 2009, p. 25).



Figure 37. Dotterel, Awarua Bay, New Zealand (Rees, 2013).



Figure 38. Torea, New Zealand (Potton, 2009, p. 25).

- Advantages

- (1) Reduce the extent of coastal erosion during storms and build up sand dunes.
- (2) Prevent wind erosion by decreasing wind speed at ground level (Auckland Council, n.d.).
- (3) Dunes also improve and maintain coastal water quality, working as a filtration system (Department of Conservation, n. d.).
- (4) Provide habitats for a variety of unique plants and animals, including rare and endangered species, thereby increasing biodiversity (“Sand dune stabilization,” 2016).

There are several species of birds, such as the fairy tern (Figure 36), dotterel (Figure 37), torea (Figure 38) and pipit (Figure 39), that live among New Zealand’s dunes and sand spits (Peart, 2009). Some species are now highly endangered due to heavy modification of dune habitats in the country. The New Zealand fairy tern (taraiti), is the rarest breeding bird weighing around 70 grams and had a population of only three pairs in 1983 and ten pairs after 1983 (Peart, 2009). The northern New Zealand dotterel (tuturiwhatu), was once a widespread species and could be seen all over the country, but now there are only about 1,500 remaining (Peart, 2009).



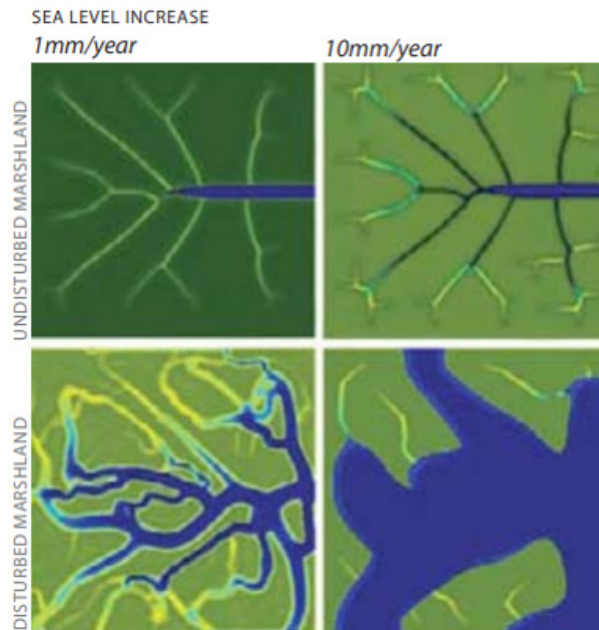
Figure 39. Pipit, Antipodes Island, New Zealand (Boyle, 2011).

3.2.2 Salt marshes

A salt marsh, also known as a tidal marsh, is a coastal ecosystem in the upper coastal intertidal zone between the land and ocean which is flooded daily by tides (“Salt marsh,” 2016). In New Zealand, most salt marshes occur on low-energy coastlines, normally at the mouth of estuaries where there are little wave force and high sedimentation (“Salt marsh,” 2016). The characteristics of daily tidal flow in coastal salt marshes distinguishing them from terrestrial habitats, playing an important role in sediment and nutrient delivery, and providing a water supply to marshes (“Salt marsh,” 2016). Figure 40 shows the salt marsh on the shores of Ohiwa Harbour in New Zealand, which is a conservation area. Salt marshes are vital habitats that play important roles in coastal protection and fishing industry. Tides carry in nutrients that stimulate plant growth in the marsh and carry out organic material that feeds fish and other coastal organisms. Organic material accumulates over time, forming a compact layer called peat (New Hampshire Department of Environmental Services, 2004). Salt marshes can protect coasts by keeping pace growing rising sea levels and also reduce the speed and energy of waves before they reach land (New Hampshire Department of Environmental Services, 2004).



Figure 40. Salt marsh, Ohiwa Harbour, New Zealand (Hughes, 2011).



Research into the role of tidal salt marshes was conducted by Duke University (in the US) (Stephenson & Turner, n.d.). Its main idea is that marshes can act as a natural buffer to absorb rising sea levels and mitigate coastal erosion. In Figure 41, sea water is filled with blue colour and salt marsh is filled with green colour. When the sea levels increase from 1mm to 10mm each year, the undisturbed marshland (top images) may experience little change while disturbing half the vegetation or just 5% of the plants and reducing sediment supplies (bottom images), it causes substantial changes (Stephenson & Turner, n.d.). Based on this study, Duke University suggests to reverse-engineer former human structures into marshlands to act as a natural buffer against sea level rise. This research is very inspirational for me and I have included the salt marsh as an important part of my project.

Figure 41. Marshland can absorb rising sea levels (Duke University, as cited in Stephenson & Turner, n.d.).

3.2.3 Softened coastline



Figure 42. Resilient Coastline, Palisade Bay, NY/ NJ, USA (Princeton University, 2010).

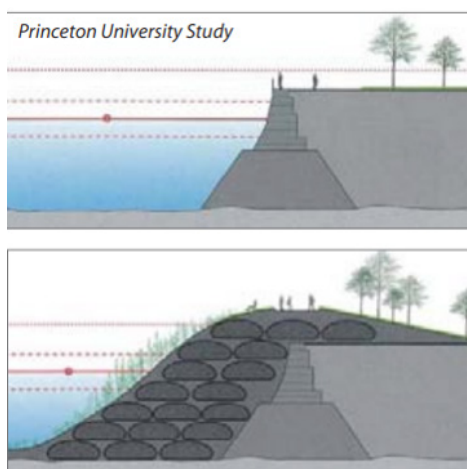


Figure 43. Softened coastline section (Princeton University, n.d.).

As cited in Stephenson and Turner (n.d.), the School of Architecture at Princeton University conducted a study about increasing the resilience of Palisade Bay in the northeastern US in 2010 (Figure 42). Hard engineering options were discarded in this research: they tested soft solutions and developed diverse small-scale interventions. An intervention, softened coastline (Figures 43 and 44), was developed under this resilient concept. This was a way through softening hard walls by building a wide base within the water and creating a soft coastline up to a height. These newly created green spaces would absorb most of the wave energy in storm surges, mitigating the effect of sea level rise to a large extent. The natural ability of the coast to mitigate the adverse effects of extreme conditions (e.g. storms, rising sea level) are greatly improved in an innovative and smart way in this design. Aside from the function of protecting the coast from natural hazards (erosion and sea level rise), a softened coastline will beautify the coastal environment and also create opportunities to enhance biodiversity. These studies are very inspirational for me; hard protection defences that are weak and ineffective in my research site are replaced with this soft protection. This is done to increase the resilience of the coastline in extreme conditions.



Figure 44. Softened coastline perspective (Princeton University, n.d.).

3.3 Case Studies

3.3.1 Artificial Reef Balls

- Narrowneck Beach, Gold Coast, Queensland, Australia
 - Gran Dominicus Resort, Dominican Republic
- Proposal Study for Orewa's Multipurpose Reefs, New Zealand

3.3.2 Sand Engine

- Zandmotor, Netherlands, 2011

3.3.3 Dune Restoration

- Papamoa Beach, New Zealand, 1998

3.3.4 Compartmentalisation Concept

- Flemish Coast, Belgium, 2012

3.3.5 Resilient + The Beach

- Jersey Shore, New Jersey, USA, 2014

3.3.1 Artificial Reef Balls



Figure 45. Aftermath of the 1967 cyclones at Surfers Paradise (Jackson & Hornsey, 2003).



Figure 46. Storm erosion at Narrowneck in March 1996 (Jackson & Hornsey, 2003).

Artificial reef balls mimic natural reef systems with marine-friendly materials, to create new fish habitats and scuba diving sites. There are more than 70 countries and 4,000 projects throughout the world using the technology (The Reef Ball Foundation, 2016). Many case studies demonstrate the great performance of these balls in protecting a beach from erosion. Unlike conventional engineering technologies (e.g. seawall, groynes and jetties), which usually cause negative effects to the coastal environment, the artificial reef ball is a more environmentally-friendly way to protect a beach by dissipating wave energy and providing diverse habitats for biota. Case studies have been selected from three different countries.

- **Narrowneck Beach**
Gold Coast, Queensland, Australia, 2000

The world's first multi-purpose submerged reef project is located at Narrowneck at the northern end of Surfers Paradise, on Australia's Gold Coast (Figure 47). The large artificial submerged reef (up to 350 tonnes) is constructed of sand geotextiles, which have a 25-year lifespan (Jackson & Hornsey, 2003). The aims of this project were to widen the beach and dunes along the Surfers Paradise Esplanade and to improve the surfing climate at Narrowneck.

The Gold Coast is one of the most popular tourist destinations in Australia and its economy is dependent on the tourism industry. The erosion problem at Narrowneck was so serious that only a thin strip of sand was left along the shore. In 1967, seven cyclones hit this section of coastline causing severe and extensive damage to Gold Coast beaches and beachfront properties (Figure 45). This event caused the worst storm erosion recorded in history in Australia. Before the construction of the reefs in 2000, the beach was not wide enough to resist storm erosion, as seen in Figure 46, which shows a photo taken at high tide.

Coastal protection was proposed as part of the Gold Coast Beach Protection Strategy to solve this issue (ASR Ltd, n.d.). A socio-economic assessment found that for every dollar spent on enhancing Narrowneck Beach, \$60-80 would be returned via tourism-related benefits (Raybould & Mules, 1998). In order to continue attracting tourists, it is very important and worthwhile to protect the sandy beach of Narrowneck. Extensive studies have shown that reefs are effective in reducing wave energy and the Narrowneck reef protects from coastal erosion along the shore (Jackson & Hornsey, 2003).

The Narrowneck submerged reef project was very successful at retaining sand that was pumped onto Surfers Paradise Beach. Up to 90 percent of wave energy is dissipated by the reef, and a salient was formed in the lee of the structure at the beach, causing a width increase of around 10-20 meters within two years. New recreational activities (Figure 48) and new habitats (Figure 49) were created by the reefs.



Figure 47. Aerial view of Narrowneck Reef (Vroom, 2013).



Figure 48. Diving at Narrowneck (Edwards, 2014).



Figure 49. Narrowneck Reef (Banks, 2008).



Figure 50. Three-row submerged reef balls (Harris, 2001).



Figure 51. Gran Dominicus Resort in 1998 (Reef Beach Company, 2011).



Figure 52. Gran Dominicus Resort in 2001 (Reef Beach Company, 2011).

- **Gran Dominicus Resort**
The Dominican Republic, 1998

The Gran Dominicus Resort is located on the south Caribbean coast of the Dominican Republic near Bayahibe (east of Santo Domingo and LaRomano) (Harris, 2001). It was awarded a Reef Ball Foundation Project of the Year Award in the category of Innovative Uses of Reef Balls for their pioneering work (Reef Ball Foundation, n.d.).

The Gran Dominicus project was completed in the autumn of 1998 and performed exceedingly well by continuing to gain sand in the first two years and remaining stable in the second two years. The shoreline is oriented east-west, with predominantly southeast wind and waves, resulting in the current and sand transport from east to west (Harris, 2002). The design of the submerged reef ball system consisted of three segmented sections, using three rows of reef ball units for each segment (Figure 50) (Harris, 2001). Figures 51 and 52 shows the increased beach width as a result of the project from 1998 to 2001 at the center of the site looking west. When waves travel, they pass over these submerged reef balls and breaks over them rather than reach the beach directly. Around 60 percent of wave energy was reduced by the structures, and sand naturally accumulated along the shore without sand renourishment.

Reef balls act as a submerged breakwater, but in a more environmentally friendly way. Aside from the role of erosion protector, these reef systems provide a new habitat for biota in the sea to support a healthy reef ecosystem within a few months after the installation. The submerged reef systems provided an excellent sand beach for recreation and tourism, with no adverse effects to the environment or adjacent coastline.

- **Proposal Study for Orewa's Multipurpose Reefs
Rodney District, New Zealand**

This multipurpose reef proposal by ASR Ltd was prepared for the Orewa Beach Reef Charitable Trust and the Rodney District Council in 2009. Orewa is a popular holiday destination with a population of around 7,300 ("Orewa," 2016). It has experienced coastal erosion for a long period of time with nearly no dry beach during high tide.



Figure 53. Proposed reef system in Orewa (ASR Ltd, 2009, p. 123).

One integrated reef system (Figure 53), comprised of four separate reef systems, was designed for preventing erosion at Orewa (ASR Ltd, 2009). Each system of reefs would protect and enhance approximately 600 m of beach front; four sets of reefs would be required to protect and enhance the entire 2.4 km of Orewa Beach (ASR Ltd, 2009). Beach width is expected to be significantly increased by salient formation of around 150 m after installing the reef system (ASR Ltd, 2009). The crest height of the reef system would be equal to the mean low water spring and 1.2 m below the mean sea level. The reefs would be fully submerged during all but the lowest tides (<1% of the time), with very minor effects on the visual landscape. Geotextiles were selected as the material for constructing the reef system for safety considerations, having a 20 to 30-year life expectancy (ASR Ltd, 2009). Monitoring to determine the efficacy of the design would commence with the construction of the first reef system and would continue for up to three years after the completion of construction (ASR Ltd, 2009).

However, this high-density artificial reef system would create some barriers for navigation (shipping and boating access). Having taken this reason into account, my suggestion would be to cancel one of the reef systems that near the navigation access to maintain access to the navigation route. Combined with natural forces (like longshore drift and currents) this would further help to relocate the accumulated sand along the shore. The biggest project is working with nature. The proposal for the Orewa Beach multipurpose reefs is similar to the previous two case studies (Narrowneck Beach and Gran Dominicus Resort) in terms of the context. All of these three sites are popular holiday destinations. Narrowneck Beach and the Gran Dominicus Resort had also suffered from erosion before installing reef balls.



Figure 54. Mount Maunganui's artificial surf reef before its removal (Bay of Plenty Times, 2014).

Not all artificial reef projects have performed as well as original expectations. Mount Maunganui's artificial reef (Figure 54), New Zealand's first submerged artificial reef project, has now been removed because of the poor surf breaks produced by the reefs and the potential risk for swimmers from the rips, especially in the Tay Street area ("Mount Maunganui," 2016). This project, cost \$1.5 million to be built from 2005 to 2008, did not function as intended, and was criticised by surfers and the public (Bay of Plenty Times, 2014). According to the Bay of Plenty Times (2014), the reason for its unsuccessful performance is that the reef was not constructed according to its original design; errors were made during its erection such as under-filling of the geotextiles bags.

I am inspired by these case studies about using artificial reefs to address beach erosion. Artificial reefs have obvious advantages in mitigating coastal erosion by dissipating wave energy and have proved to be an efficient solution for beach erosion control. They also provide new habitats for biota in the sea, contributing to biodiversity enhancement. Additionally, the submerged reefs cause no adverse impacts to the adjacent coasts and also create more recreational opportunities for residents and travellers, such as snorkelling and diving.

However, there are some criticisms of artificial reefs. Firstly, it is the high installation cost. Secondly, the weather conditions following the project deployment, like storms, hurricanes and the amount of sand moving in the littoral system, will affect the efficiency of artificial reefs (Harris, n.d.). Thirdly, the installation method is susceptible to adverse weather conditions. And fourthly, they are also vulnerable to damage from boaters, fishermen, divers and snorkellers.

3.3.2 Sand Engine

- **Zandmotor, Netherlands, 2011**

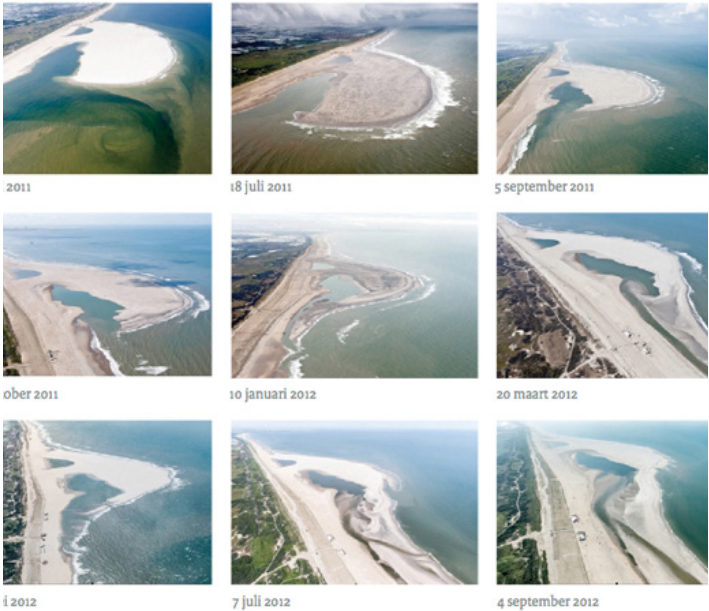
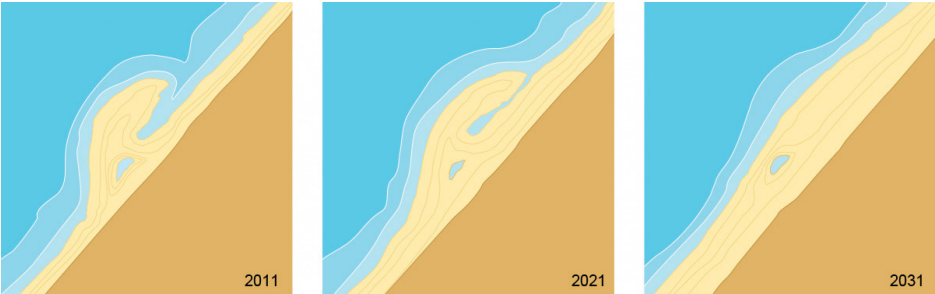
The Zandmotor project is an innovative alternative method of coastal protection implemented by Rijkswaterstaat (an agency in the Netherlands) and the Province of South Holland between Rotterdam and The Hague. It represents the idea of building with nature, as the sea was invited to be a contributor. Twenty-one and a half million cubic meters of sand were dumped into the North Sea in 2011, creating the Zandmotor (Sand Engine) (Bilak, 2013). Construction of the artificial peninsula coast cost €70 million and its 128 hectare area is equal to 256 football fields (Bilak, 2013). Within the next 20 years, natural forces (wind, waves and sea currents) will help to distribute the huge amount of sand along the 20-kilometer stretch of shoreline, creating a wider beach and new recreational areas (Figure 55) (Bilak, 2013). It is predicted that beach nourishment will be unnecessary for the next 20

years. The process is a dynamic extension of the coast; this newly created peninsula will slowly transform into a spit and lagoon (Satellietgroep, n.d.). Figure 56 shows the changes to the coastline as a result of the dynamic sand engine. The creation of a stable ecosystem is another benefit of this project. The giant dunes were often visited by seals, and the new lagoon is covered with seaweed, creating a new habitat for fish. The Zandmotor has already become a popular destination for surfers and kite surfers (Bifak, 2013).

Living below sea level need to reinvent coexistence of man and water, develop new insights in order to realise a healthy and sustainable future (Satellietgroep, n.d.). The Zandmotor is an important example in dynamic coastal management, and may become a model for similar projects along the Dutch coast. This approach proves that the largest projects are best managed by working in harmony with nature, not against it. This core idea of working with nature inspires me a lot.

(Left) Figure 55. Zandmotor projections over the years 2011-2021-2031 (Bernau, 2011).

(Right) Figure 56. Zandmotor (RWS, 2011-2012).



3.3.3 Dune Restoration

- **Papamoa Beach, New Zealand, 1998**

In the early 1990s, coastal storms severely eroded the dunes at Papamoa Beach, leaving large erosion scarps within a few meters of some property boundaries (Figure 57). The restoration of native sand-binding species on the seaward duneface has successfully restored natural dune building and repair processes, resulting in seaward dune advance of 10-15 m between 1998 and 2004. Figure 58 shows a seal that was spotted on the wide beach on a stormy day. This dune advance has created a much wider dune with a more gentle, vegetated and resilient front slope to help buffer from storm erosion (Figure 59). Additionally, recent data gathered from Papamoa beach shows that this dune construction will completely offset the effects of +118cm of sea level rise predicted by the IPCC 5 AR through to at least 2100, by the SimCLIM2013 Coastal Erosion computer model (Jenks, 2014).



Figure 57. Degraded frontal dune at Papamoa East in June 1997 (Ministry for the Environment, n.d.).



Figure 58. A seal was spotted in the sand on a stormy day (Bay of Plenty Times, 2014).



Figure 59. Dunes at Papamoa East after restoration work (Ministry for the Environment, n.d.).

3.3.4 Compartmentalization Concept • Flemish Coast, Belgium, 2012

Low-lying coastal zones, being the interface between the land and sea, are vulnerable to coastal erosion and flooding during storms. On the Belgian coast, climate-induced coastal erosion predicted to cause the loss of 17 to 50 percent of beaches by 2100 (Van der Biest, Verwaest et al., 2009). The Belgian coast was the most urbanised coastal region in Europe during the beginning of the 19th century, up to 88 percent of the Flemish coastline is protected by dykes and beach nourishment (Eurosion, 2004). Climate-related challenges on the Belgian coast are so significant and urgent that it is necessary to find a new equilibrium, and this demands an innovative approach and an integrated vision on local climate adaptation and socio-economic development.

To answer these climate-related challenges, the CcASPAR project concentrates on a new concept of “compartmentalization” as a tool to create flexibility at a local scale on the Flemish coast. With this concept, the current system and its safety levels are revisited. New embankments are added to divide the coastal zone into different compartments, each one with its own water management. Such division creates the possibility to rescale the adaptation debate. Each compartment can be analysed individually, considering its land use, socio-economic characteristics and landscape. If the existing system is to be maintained, techniques (such as dyke reinforcement, new pumps and increased water supply) are in order (Lierman, Waegemaeker, & Allaert, 2012).

The new compartmentalization concept has several benefits. Firstly, it offers opportunities to balance the system and its safety levels at a local scale, avoiding implementing extreme protections where they are unnecessary or undesirable. Secondly, it creates opportunities to build with nature. By redefining the system, this natural adaptation can be put to use. For each compartment, strategies can be developed that integrate natural dynamics and local socio-economic development (Lierman, Waegemaeker, & Allaert, 2012).

Differing from traditional urban coastal landscapes that are relatively monotonous, this new coastal region—a collection of compartments—will be a new interface between the land and sea, capable of mitigating climate-related impacts in the long term (Lierman, Waegemaeker, & Allaert, 2012). As seen in Figure 60, the left caricature shows current Flemish coast, and the right one shows a new coastal landscape created by compartmentalization concept. This innovative concept increases the flexibility of the Belgian coast as a whole. It is applied to my research project, serving to make the appropriate decisions for different compartments of the site.

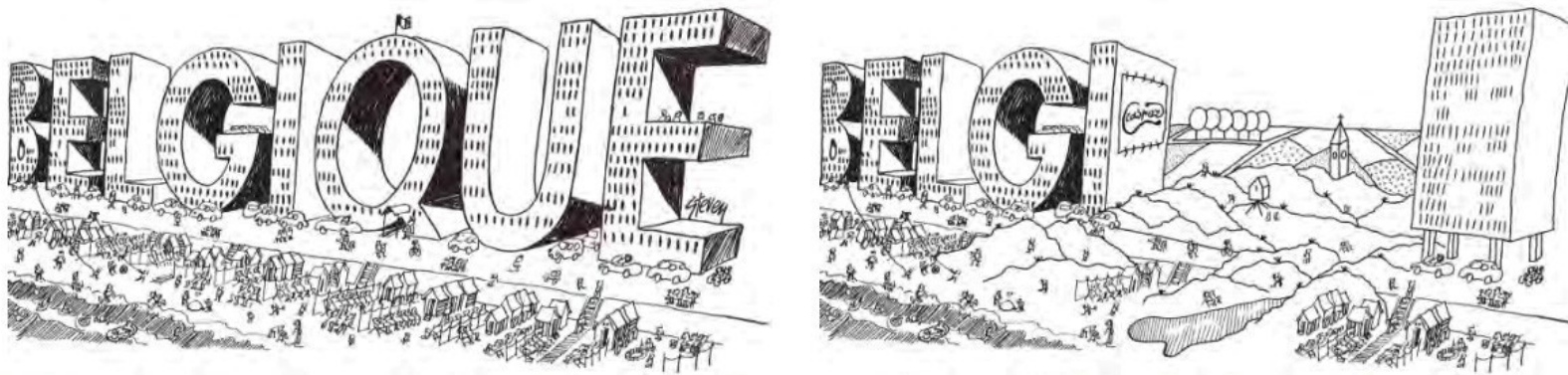


Figure 60. Compartmentalization concept on Flemish Coast (CcASPAR, 2012).

3.3.5 Resilient + The Beach

- Jersey Shore, New Jersey, USA, 2014

Jersey Shore tourism plays a significant role in New Jersey’s economy and in the regional cultural identity. Like any other coastal areas, New Jersey is facing significant challenges in water management. On October 29th of 2012, Hurricane Sandy struck coastal areas in the New York/New Jersey area, causing massive damage to beaches, coastal infrastructure and residential areas from storm surge, flooding and strong winds. Extreme weather will become increasing frequent due to climate change, which will increase challenges for coastal cities.

The headlands project was proposed by Sasaki Associates with Rutgers University and Arup in 2014 to enhance the resilience of the Jersey Shore (Sasaki/Rutgers/Arup, 2014). It introduces a layered strategy with integrated social and ecological components to address water management challenges. A new hybrid boardwalk-dune infrastructure along the shoreline is highlighted in the proposal (Figure 61). The organic boardwalk honours social functions while redesigning it to create dunes along its edges that can protect the area behind it. Unlike traditional boardwalks, which normally have straight edges, this proposed boardwalk’s shape is more like a rhomboid. The design inspiration of the boardwalk comes from the existing boardwalk’s unique wooden herringbone pattern and the wooden sand fences that are used to structure dunes (Figure 62) (Sasaki/Rutgers/Arup, 2014). This special design is expected to trap more sand than a conventional boardwalk that normally has straight edges. The area between the boardwalk and water includes a series of sacrificial dunes, tidal pools and a primary dune (Figure 63) (Sasaki/Rutgers/Arup, 2014).

EVOLUTION: DUNE-BUILDING BOARDWALK OVER TIME

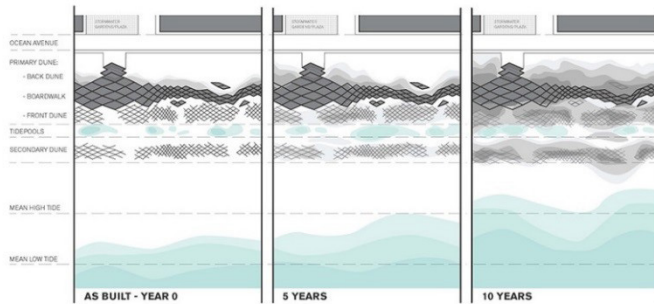


Figure 61. Organic boardwalk form and topography (Sasaki/Rutgers/Arup, 2014).

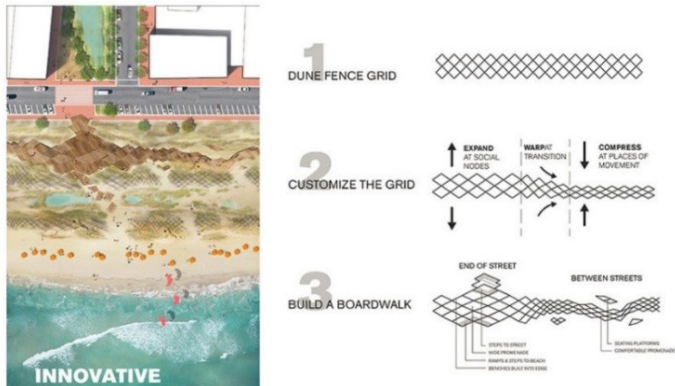


Figure 62. Design inspiration of organic boardwalk (Sasaki/Rutgers/Arup, 2014).

The boardwalk offers an opportunity to rethink the existing beach edge. A more organic boardwalk form and topography can create a new relationship with beachfront development and promote an ecologically healthier landscape (Sasaki/Rutgers/ARUP, 2014). The design of the boardwalk expands social interaction through the creation of seating, steps and intimate edges while providing a new shape to capture sand and form dunes over time, creating protection and habitat area for beach wildlife (Figure 64) (Sasaki/Rutgers/ARUP, 2014).

The inspirational part of this project for me is the design of the organic boardwalk. The ingenious design integrates ecological and social functions, helping coastal community adapt and strengthen in the face of ongoing sea level rise and storm threat.

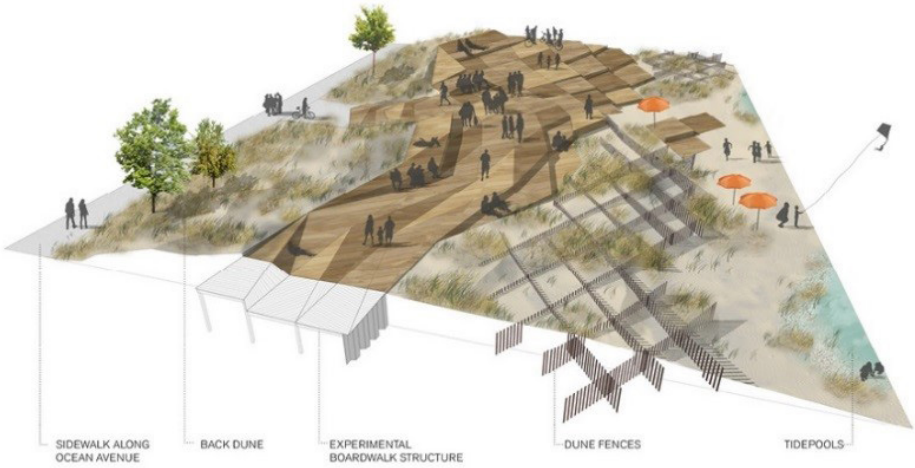


Figure 63. Dune-building boardwalk perspective (Sasaki/Rutgers/Arup, 2014).



Figure 64. Organic boardwalk perspective (Sasaki/Rutgers/Arup, 2014).

4 Site Introduction and Analysis

Site Confirmation

Site Context

Site Analysis

4.1 Site Confirmation



Figure 65. Location of Auckland region (“Auckland Region,” 2015).

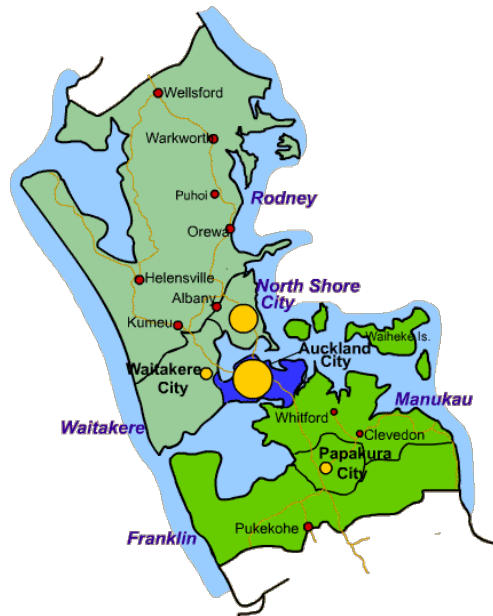


Figure 66. Auckland regional map (New Zealand Communities, 2000).

4.1.1 Spatial Context

- Auckland’s Coastline

There are sixteen regions in New Zealand, and the Auckland region (Figure 65) is the country’s largest urban area with the biggest population (34 percent of the nation’s residents) and economy (‘Auckland Region’, 2015). It is comprised of metropolitan areas, smaller towns, rural areas and the islands of the Hauraki Gulf. The Auckland region encompasses seven districts (Figure 66): Auckland City, North Shore City, Rodney District, Waitakere City, Manukau City, Papakura District and Franklin District. The total coastline of Auckland is around 3,100 kilometers long (Auckland Council, 2016), and is a significant resource in terms of its recreational, aesthetic, ecological and commercial values. It is home to a variety of wildlife and scenery, however, they are vulnerable to coastal erosion. The Auckland Council (2016) states all of Auckland’s coastal areas, like beaches, dunes, cliffs and estuaries, can be subject to erosion or other natural coastal hazards.

There are two types of coastlines in Auckland: beaches and cliffs (ARC, 2006). Auckland’s west coast is dominated by beaches with intermittent stretches of cliff around the Waitakere coastline; the east coast and the Hauraki Gulf Islands contain both beaches and cliff coastlines; and estuaries and harbours are predominantly soft cliffs with smaller regions of hard cliffs and beaches (ARC, 2006).

- Beaches in Auckland

There are many beaches throughout Auckland, from black beaches to sheltered golden bays. Beaches are very important for Aucklanders and are deeply ingrained in people's life and culture. Popular beaches include Takapuna, Milford, Cheltenham and Long Bay in the North Shore; Tamaki Drive, Mission Bay and St Heliers in the east of Auckland; and Piha, Muriwa and Karekare on the west coast. These beaches are significant places for a variety of recreational activities such as swimming, walking, horse riding, surfing, having picnics and barbecuing. Beaches are also vital buffer areas between the land and sea, reducing the coastal hazard to inland areas. However, the majority of Auckland's beaches are at risk of erosion and sea level rise. In this research, beach erosion in the Auckland region is chosen as the research focus.

- Types of beach in Auckland

Beaches are deposits of sand or gravel situated at the interface between the land and sea, and are shaped by hydrodynamic processes (waves, tides and currents) and winds (ARC, 2006). The changes to beach coastlines are a result of short-term fluctuations in the beach profile and long-term retreat or accretion (ARC, 2006). Beach erosion is a permanent landward translation of the beach profile (ARC, 2006).

In terms of shapes and geographical locations, beaches are classified into four main forms: barrier spits (Figure 67), pocket beaches (Figure 68), harbour beaches (Figure 69) and open coast beaches (Figure 70) (ARC, 2006). Barrier spits are the most dynamic and unpredictable of beach types, separating harbours, estuaries and river inlets from higher energy surroundings. Pocket beaches are semi-closed systems confined by headlands on both sides, almost shifting no sand with adjacent shorelines. Harbour beaches are made up of the sediments derived mostly from local areas, like surrounding cliffs, bank erosion and/or shell material. Open coast beaches are normally high energy and are open to the sea, having no protection from the natural power of the ocean (ARC, 2006). My research focus is the pocket beach in Auckland region.

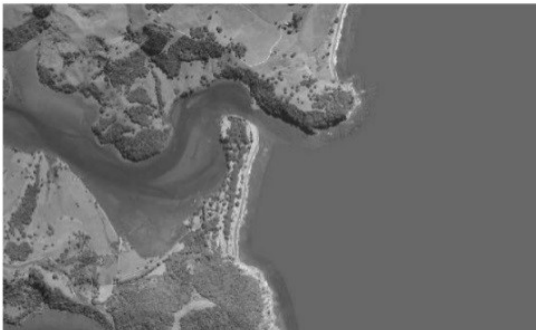


Figure 67. Barrier beach- Wenderholm (ARC, 2006).



Figure 68. Pocket beach- Maraetai (ARC, 2006).



Figure 69. Harbour beach- Pt. Chevalier (ARC, 2006).



Figure 70. Open coast beach- Piha (ARC, 2006).

4.1.2 Site Confirmation

ARC (2006) states that Orewa Beach is susceptible to coastal erosion under storm conditions. Figure 71 shows the likely widths of Orewa’s coastlines susceptible to erosion is 13 meters and the possible erosion width is 28 meters (ARC, 2006). Many other news articles (Figures 72, 73 and 74) have also pointed out severe coastal erosion problems currently in Orewa.

Beach No.	Beach Name	Length (km)	Easting - Midpoint	Northing - Midpoint	“Likely” erosion width from vegetation line (m)	“Possible” erosion width from vegetation line (m)	“Unlikely” erosion width from vegetation line (m)
	Orewa Beach	2.76	2662244	6511551	13	28	46

Figure 71. Widths of Orewa’s coastline susceptible to erosion (ARC, 2011).

Orewa Beach eroded by tidal surges

Updated at 1:07 am on 25 September 2013



Orewa Beach, north of Auckland city, will remain closed to the public on Wednesday, after tidal surges caused significant erosion overnight. A swell of 4m struck about 11pm on Tuesday.

Civil Defence says council inspectors will visit the beach on Wednesday morning to see if it is safe to re-open.

Figure 72. Photo from a news article from Radio New Zealand showing eroded Orewa Beach (Radio New Zealand, 2013).

Warning on Orewa Beach erosion

By Wayne Thompson

5:30 AM Friday Nov 12, 2010

Environment Local Government New Zealand ... ☆ f 47 t in

One of Auckland's most popular beaches could be hit by severe summer storm damage because of five years of neglect by authorities, says Destination Orewa Beach.



The local association yesterday called on the Auckland Council to urgently restore sand levels on the 3km stretch of sand.

Figure 73. Photo from a news article from NZME showing summer storm damage Orewa Beach (Estcourt, 2010).



Council northern parks manager Martin van Jaarsveld, Hibiscus and Bays chairwoman Julia Parfitt and deputy mayor of Auckland Penny Hulse view storm damage on Orewa Beach in 2013. « Previous Next » 1 of 8

Figure 72. Photo from a news article from Rodney Times showing storm damage on Orewa Beach (Dickeyd, 2013).

4.2 Site Context

The name “Orewa” refers to a place of rewarewa (a native New Zealand tree). “O” means “place of” in Maori, and “rewa” is a contraction of rewarewa (New Zealand History, n.d.). Orewa originally referred to the river rather than the beachfront. In 1856 Captain Isaac Rhodes Cooper of the 58th Regiment occupied land and called his home Orewa House (New Zealand History, n.d.). Orewa (Figures 75 and 76) is a popular holiday destination with a population of more than 7,300, and it is also one of the fastest growing towns in New Zealand and with some of the most expensive housing prices in Auckland (‘Orewa’, 2016), a perfect place for a day trip or a long weekend escape (Destination Orewa Beach, 2013). Orewa’s 3 km of sandy beach and open public spaces are considered its most significant natural resources in this area (Peart, 2009).



Figure 75. Aerial photograph of Orewa (Harcourts, 2008).

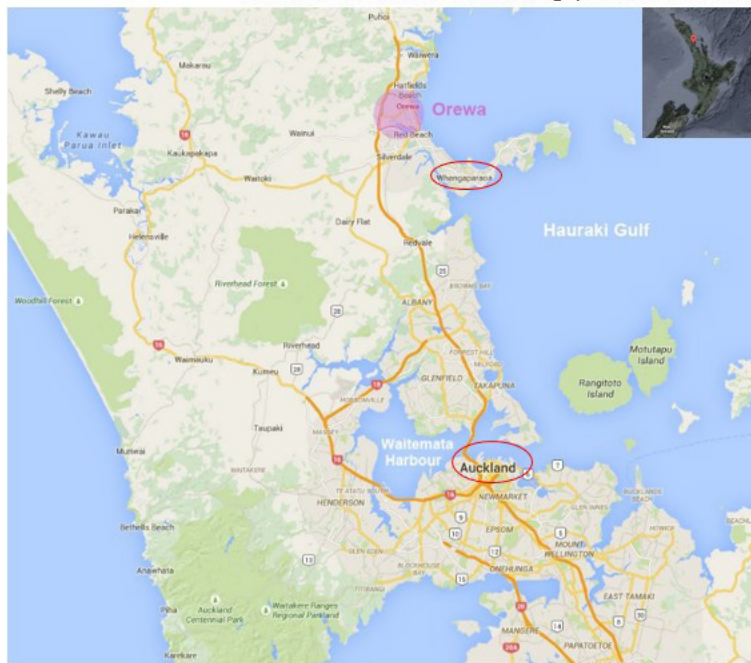


Figure 76. Orewa at dusk (McCormick, 2014).

- **Site Location**

Orewa is located on the Hibiscus Coast, just north of the Whangaparaoa Peninsula and 40 kilometers north of central Auckland (“Orewa,” 2016). Figures 77 and 78 show the location of Orewa.

North of the base of the Whangaparaoa Peninsula



North of central Auckland: 40km; 20min drive

Figure 77. Orewa location (Google Maps)

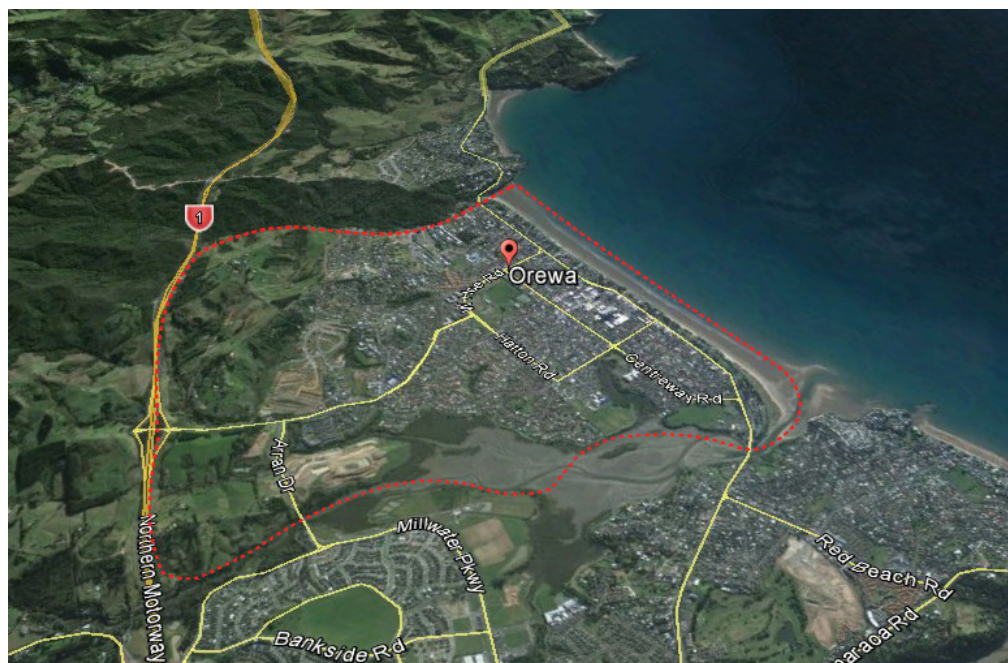


Figure 78. Site looking from south-west (Google Earth)

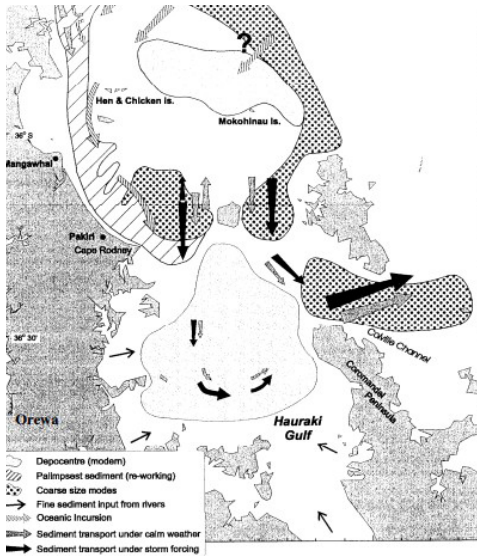


Figure 79. Sediment transport and deposition regime in the Hauraki Gulf (after Manighetti & Carter, 1999).



Figure 80. Prevailing wind direction and strength in New Zealand (Mckenzie, 1958).

• Overview of Coastal Processes in Orewa

a. Sediment Source

Raudkivi (1981) found that the sediment at Orewa Beach is mostly sourced from local rivers and streams. Additional sediment inputs are from eroding cliffs on the Whangaparaoa Peninsula and Waitemata sandstone reefs (Manighetti & Carter, 1999).

b. Sediment Transport

Origin of the Orewa beach sand are not entirely Waikato Sands and Orewa is indicated as an area dominated by fine sediment inputs from rivers (Raudkivi, 1981). As shown in Figure 79.

c. Wind

Orewa receives predominantly south-westerly winds that sweep the western coast of the North and South Islands, causing a huge change in terms of sediment movement and the form of coastal zones (Figure 80) (Pennington, 2014). Compared to the west coast, the eastern coast of the North Island receives little swell, resulting in a variety of bays and coves.

d. Waves

Normally, the wave climate of Orewa is of low energy, however, it is occasionally subjected to storm conditions (ASR Ltd, 2009). The north-eastern coast has the smallest waves of all exposed coasts of New Zealand because of the predominant south-westerly weather patterns (Pickrill & Mitchell, 1979). At Orewa, wave energy is further reduced because of sheltering behind Great Barrier Island and the Coromandel Peninsula (Figure 81). Generally, waves at Orewa Beach are small with a short period created by limited local winds (ASR Ltd, 2009). Longer period swells and extreme events reach Orewa Beach through the gap between Great Barrier Island and the Coromandel Peninsula (Colville Channel) as well as to the north of Great Barrier Island and the gap between Great Barrier and Little Barrier Islands (Cradock Channel) and are the cause of the undesirable loss of beach sand (ASR Ltd, 2009).

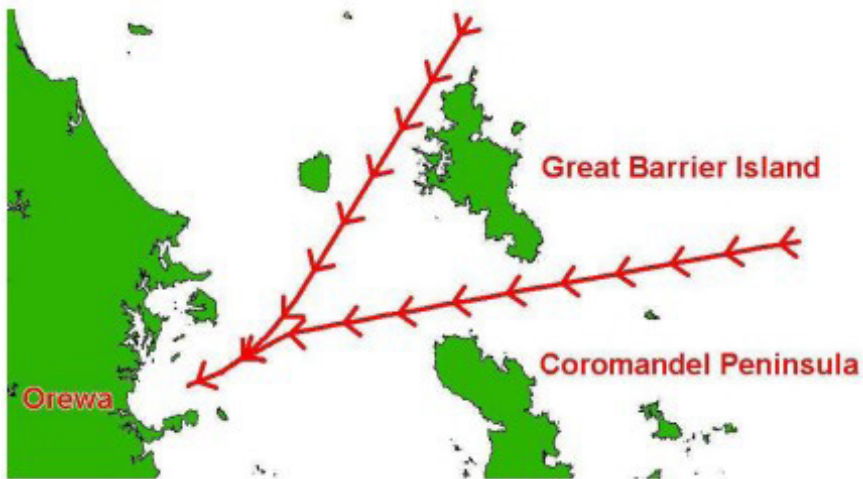


Figure 81. Wave climate at Orewa (ASR Ltd, 2009, p.9).

- **Historical Timeline**

The major historical timeline of Orewa is presented in Figure 82. In the early 1840s, the land at Orewa was first acquired from Maori and then experienced timber clearing and farming for many years (Peart, 2009). A guesthouse was first built in the original European house in 1919, and then by the early 1960s, Orewa had become a popular holiday destination, offering accommodation for approximately 3,000 people in various forms such as motels, caravans, tent sites and holiday homes (Peart, 2009). A permanent settlement began to steadily occupy Orewa, and council offices were set up there in 1974 (Peart, 2009). In the early 2000s, the 12-storey Nautilus apartment building was constructed near the beach, causing disputes about the pressures between town growth and radical natural feature changes in the shore settlement (Peart, 2009).

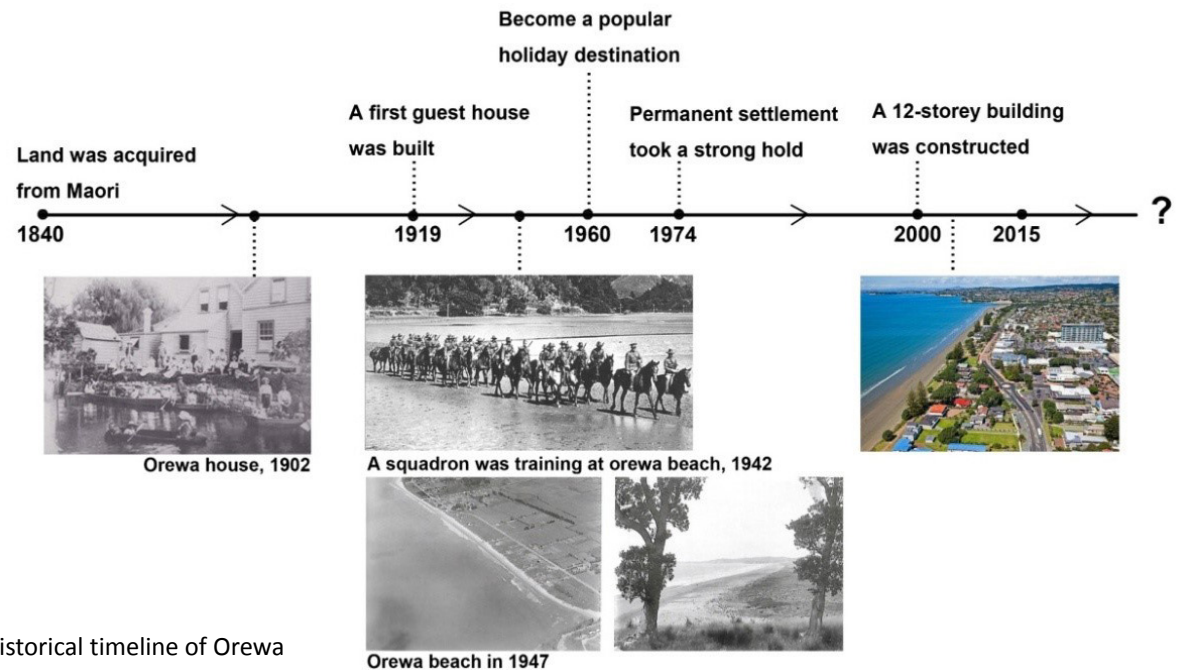


Figure 82. Historical timeline of Orewa

• Site Photos



Figure 83. Site photos in 2015.

- **Leisure Activities**

Orewa's 3 km-long sandy beach is a perfect place for most water sports like swimming, surfing (Figure 84), wind surfing, kite surfing (Figure 85), boating (Figure 86) and kayaking (Figure 87), in addition to camping and walking. People can also cycle on the Te Ara Tahuna Pathway and enjoy the amazing scenery of the Orewa Estuary (Figures 89). Many organised activities are held every year on the beach, such as the Big Dig (Figure 88), which is extremely popular with local families. This is an event that gives children the opportunity to dig in the sand on a section of Orewa Beach to find prizes. Orewa Beach is favoured by people, bringing a broad spectrum of people together, from all ages and incomes, to enjoy the coastal environment.



Figure 84. Surfing at Orewa Beach (McCormick, 2014).

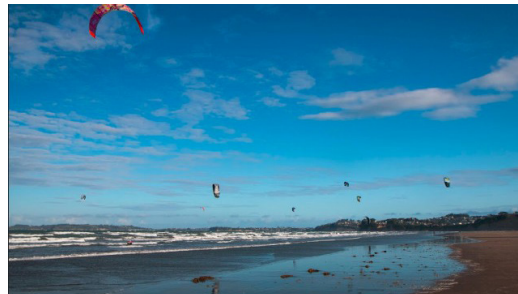


Figure 85. Kitesurfing at Orewa Beach (Wayenburg, 2014).



Figure 86. Boating at Orewa Beach.



Figure 87. Kayaking at Orewa Beach (Mitch, 2014).



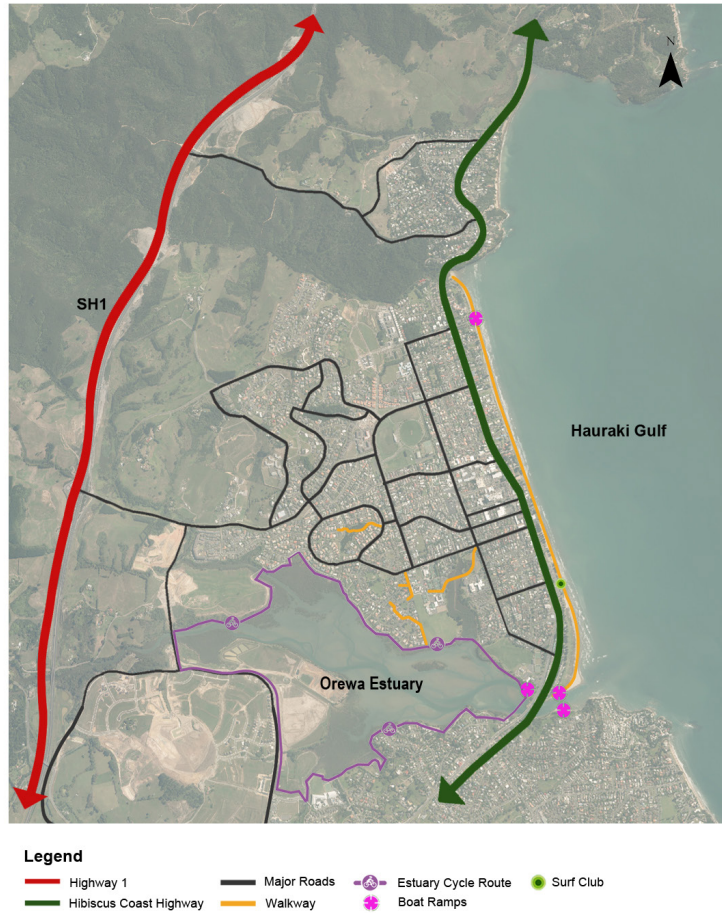
Figure 88. Big Dig event (Hibiscusmatters, 2011).



Figure 89. Cycling at Orewa Estuary (Auckland Transport, 2016).

4.3 Site Analysis

4.3.1 Site Analysis



As seen in Figure 90, Highway 1 passes inland of Orewa and the Hibiscus Coast Highway is located near the shore. Major roads indicated in black provide the access to Orewa Beach. The cycleway around the Orewa Estuary marked in purple provides recreational opportunities for people to enjoy the natural mangrove environment. There are four boat ramps along Orewa Beach, and three of them are situated at the south end around the estuary mouth. The Orewa Surf Club is located in the southeast.

Figure 90. Roads

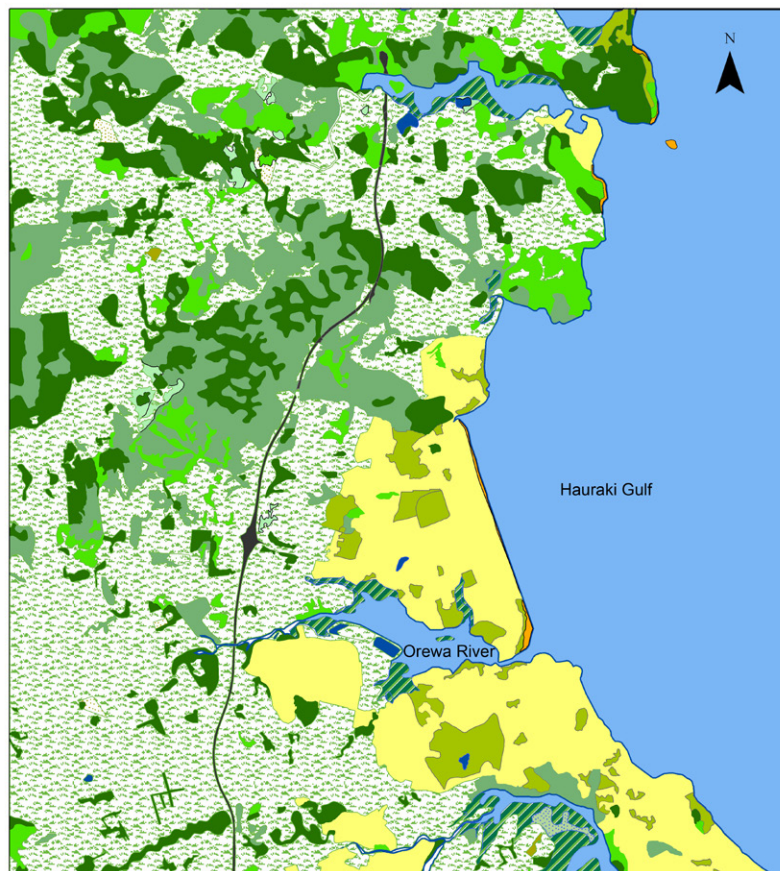


Figure 91 clearly shows (in yellow) that Orewa is an area with high-density development. Development is so close to the shore that very little green space can be seen along the coast except at the south end of the town. The loss of its natural buffering function to coastal hazards is one of the reasons why Orewa has become a fragile coast. Around the Orewa Estuary, there is a mangrove forest, which protects the community from flooding.

LCDB 2012

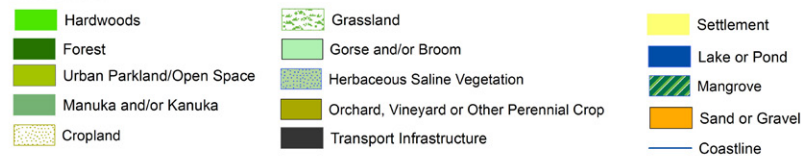
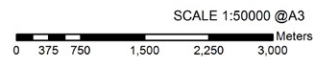
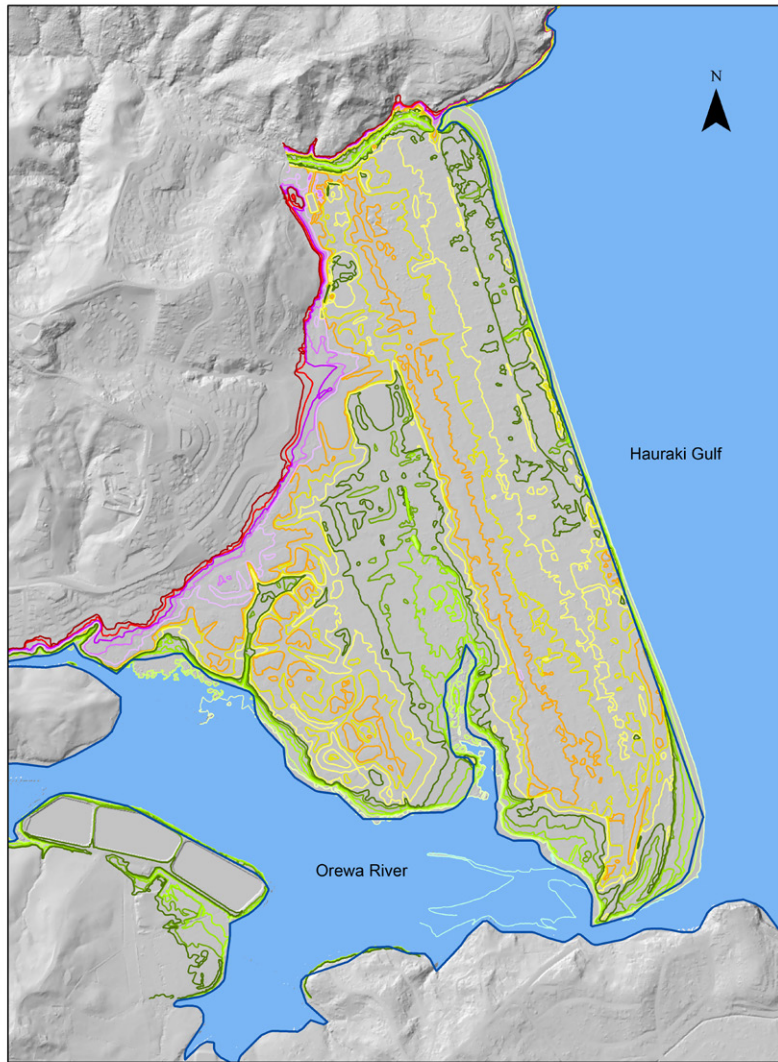


Figure 91. LCDB (2012)





ELEVATION 2006 2008

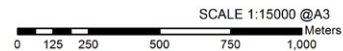
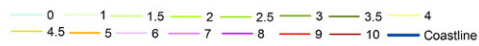


Figure 92. Elevation

Figure 92 shows that Orewa is a low-lying and flat coastal area that is very vulnerable to coastal flooding. Nearly the whole area's elevation is less than 5.5 m above sea level, with the majority of the buildings' ground floor elevation only 3.5 m above sea level with basements below that. In New Zealand, sea level is predicted to rise by around 1 m over the next 100 years.

Figure 93 shows the dramatic changes of landform in Orewa due to sea level increase from 1 m to 2 m. Many buildings (along the shore and estuary) and infrastructure in Orewa will disappear and eventually become part of the sea if actions are not taken in the future.

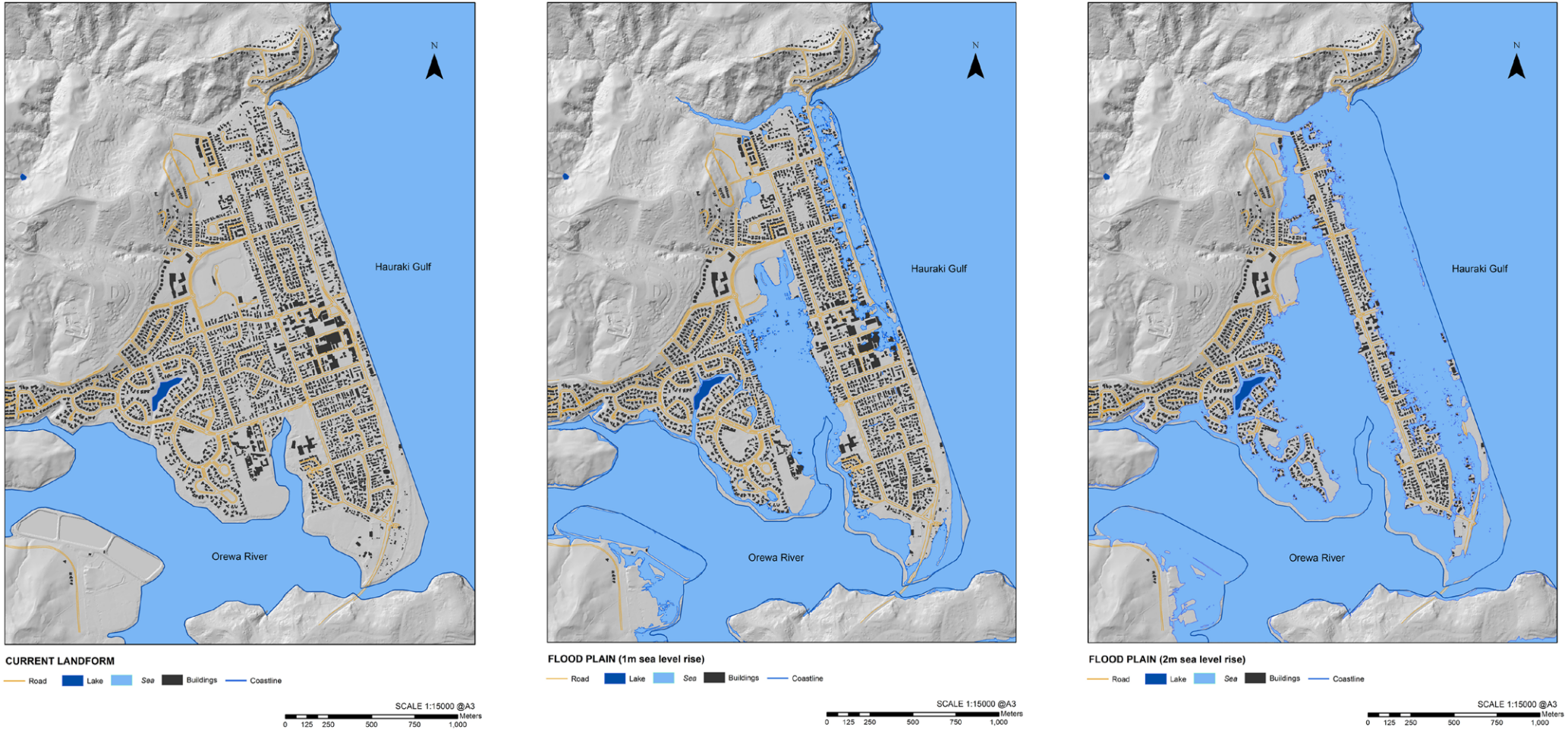


Figure 93. Changes of landform from 0m (left)-1m (middle)-2m (right) sea level rise

4.3.2 Reasons of coastal erosion at Orewa

Since early last century, a number of different factors (human activities and natural factors) resulted in the dramatic reduce of width of 'dry' beach along much of its coastline. There is nearly no visible beach when high tide comes and the situation will be worse on the storm conditions. Erosion can occur in very short time. A large amount of sand is taken away to the south end due to storms, causing severe erosion along the shore. Figures 94, 95 and 96 show the erosion occurred at Orewa Beach.



Figure 94. Erosion on the south of Kohu Street (Tonkin & Taylor Ltd, 2015, p.4).



Figure 95. Existing armour failed to prevent erosion in the north of Marine (Tonkin & Taylor Ltd, 2015, p.4).



Figure 96. Storm surge attacked coastal properties at Orewa Beach (Rodney Times, 2011).

(1) Natural Factors

Orewa was originally backed by low sand dunes, with a very gentle slope. It has a tidal range of nearly 3 meters, given the offshore slopes are around 1:100, there may be up to 300 meters of exposed sand at low tide (Figure 97) with no beach visible at high tide (Figure 98) (ASR Ltd, 2009). In addition, very little new sand is supplied because Orewa coastline is a closed sedimentary system.



Figure 97. Orewa Beach at low tide (Anthoni, 2000).



Figure 98. Orewa Beach at high tide (Anthoni, 2000).

(2) Human-Induced Factors

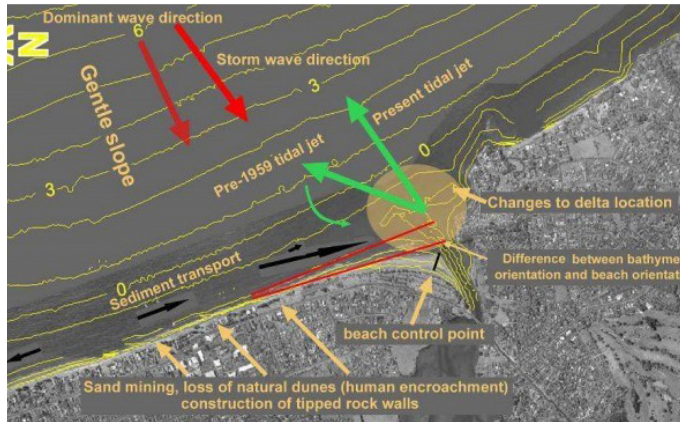


Figure 99. Human impacts of coastal erosion at Orewa Beach (ASR Ltd, 2009).

There is a long history of human modifications to the natural environment at Orewa, for example, sand mining of the onshore dunes, buildings constructed too close to the foreshore, the estuary realignment, and construction of rock seawalls and the Waitemata Groyne. By 1993, the realignment of the estuary mouth was perceived to be the major reason for erosion at Orewa (ASR Ltd, 2009). Parkin (1994) was the first one to consider the erosion reason for Orewa in a comprehensive way: the tipped rock walls, estuary realignment, loss of natural dunes and changes in wave climate all contributed to the beach erosion at Orewa. These human activities have fundamentally changed the original dynamic equilibrium of sediment transport of Orewa Beach (Figure 99) (ASR Ltd, 2009).

- Estuary Realignment



Figure 100. Location of the Waitemata Reef

Waitemata Reef (Figure 100) was once the exit for water from the Orewa Estuary, it originally went in a northerly direction hugging the land before diffusing into the Hauraki Gulf before the coastal development, producing a natural sand circulation. When sand was moved south along the shore by longshore drift, the sediment was then relocated to the north by the estuary currents (Pennington, 2014). This once natural recycling system produced a dynamic equilibrium of sand transport for Orewa Beach, resulting in large areas of dry sandy beach. In 1959, the New Zealand Navy realigned the natural estuary channel opening using explosives. This was done to modify and reduce the tidal currents, which were responsible for a number of drownings north of the estuary entrance. The erosive force caused a new configuration because an easier exit was created, which provided more access for the estuary currents. As a result, there was a change in the circulation patterns that naturally deposited sediment to the north. During large storms,

eroded sand was now deposited at the south end of the groyne and then pushed offshore creating a tidal delta (Pennington, 2014). It was the change in the estuary mouth alignment that resulted in the estuary becoming a sediment 'sink'. An average accumulation of 7,500 m³/year of sediment was estimated between May 1989 and November 1992 (ASR Ltd, 2009). Orewa became a system with sand moving out without moving in.

- Development near the foreshore

Erosion was not perceived to be an issue at Orewa until the 1960s when development began in the central part of the beach, seaward of the main road. When strong storms occurred, it threatened these early infrastructure. The central section (Figure 101) of the beach was indeed the first place to be recorded erosion (Tonkin and Taylor, 1992; 1993).

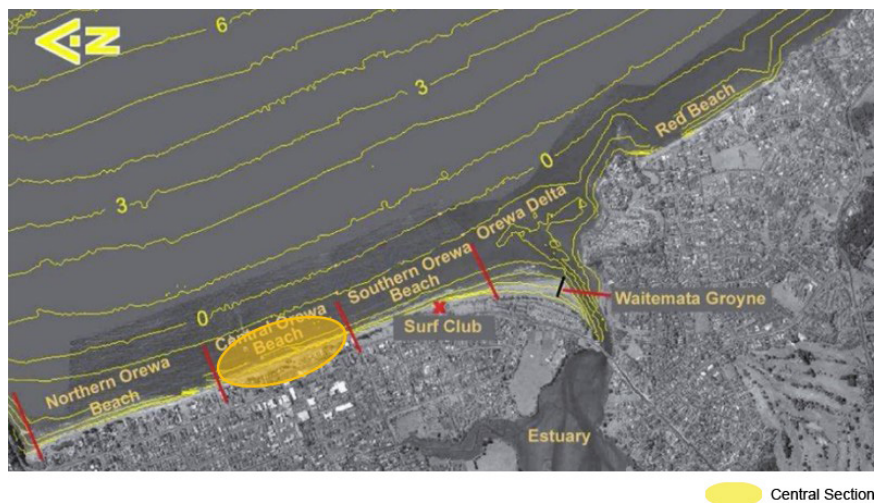


Figure 101. Central section of Orewa Beach



Figure 102. Stormwater outlets (GIS)

• Stormwater Outlets

Rainfall runoff enters the ocean chiefly via rivers, streams, lakes and lagoons. “Even the smallest streams are connected to larger rivers that carry billions of gallons of water into oceans worldwide” (EarthLabs, 2008). It also enters the sea as groundwater flow through beaches and dunes (Gordon, 2011). With extensive urbanisation, buildings, roads and other infrastructure are constructed over natural drainage paths. Rainfall which would have entered the groundwater system by infiltration is disrupted by hard surfaces and stormwater systems, leading to the increase of water flowing to oceans and the reduction of time water arrives at the ocean (Gordon, 2011). Human influences on the movement change the original healthy form of beachscape (Anthoni, 2000).

As shown in Figure 102, there are more than 10 stormwater outlets in Orewa, with eight located on the main beach. Stormwater is discharged directly onto the beach here, resulting in additional erosion (Figure 103). It is one of the reasons causing silt and clay particles there, making the beach that never seems to dry (Figure 105). In some cases, people have to jump to the other side of a gully in order to cross the stormwater outflows (Figure 104).



(Right) Figure 103. Constantly wet sand on Orewa Beach (Anthoni, 2000).

(Left) Figure 104. Stormwater drain exit at Orewa Beach in 2015.

(Middle) Figure 105. Gullies on Orewa Beach formed by stormwater outlets in 2015.

4.3.3 Protection methods to against coastal erosion at Orewa

(1) Historical efforts



Figure 105. Rock walls in 2015



Figure 106. Southern Groynes in 2015



Figure 107. Beach nourishment at Orewa (Nickey, 2015).

The Orewa community began to construct seaside barriers made of tipped rock (Figure 105) to against coastal erosion in the 1960s (Tonkin and Taylor, 1992; 1993). In 1986 the southern groyne (Figure 106) was modified and strengthened (ASR Ltd, 2009). After that, beach nourishment (Figure 107) was undertaken in 1988 by moving the accumulated sand at the southern end back to severely eroded locations and continues today (ASR Ltd, 2009). Dredging is very expensive and normally it takes several days to complete the replenishment work. According to the North Harbour News (2008), beach nourishment has happened four times since early 2007 to 2008 and has cost about \$30,000 each time. Figure 108 summarises the historical physical human works (1941-2001) undertaken to prevent coastal erosion at Orewa Beach.

Action	Quantity of Material (m ³)	Date
Sand Mining		1941 – 1944
Low Tech Groynes		1954 - 1957
Estuary channel realignment		1959
Tipped rock walls (ad-hoc)		1960 – 1980
Widening of estuary channel and construction of Waitemata rock groyne		1961
Waitemata groyne modified		1986
Central beach sand renourishment from estuary	20,000	Sept/Oct 1988
Sand renourishment of central beach, ex groyne	32,000	June 1994
ex groyne	18,000	October 1994
Sand renourishment of central beach, ex groyne	17,500	June 1995
ex groyne	10,000	October 1995
Sand renourishment of central beach, ex groyne	28,000	October 1996
Sand renourishment of central beach, ex groyne	25,000	June 1997
Sand renourishment of central beach, ex estuary	17,500	August 1998
ex groyne	12,000	October 1998
Sand renourishment of central beach, ex groyne	25,000	1999
Sand renourishment of central beach, ex groyne	25,000	2000
Sand renourishment of central beach, ex groyne	25,000	2001

Figure 108. Historical responses to beach erosion at Orewa Beach (ASR Ltd, 2009).

(2) Existing Protection Defences

We can see from Figure 109 that currently there are two main types of defences protecting the fragile coastline in Orewa: rock seawalls and dunes. The blue lines in front of the housing areas and car park are the rock seawalls, which are the major protection method now, and the dunes (marked with green lines), which protect the north and south ends of the beach. However, the existing protection system is very fragile. Seawalls have negative effects on the coastal environment, as mentioned in chapter 2. They will not mitigate erosion at Orewa but just allow for more sand to be moved offshore. As for the existing dunes, there are too flat and the area is insufficient. Fieldwork photographs are shown in Figure 110.

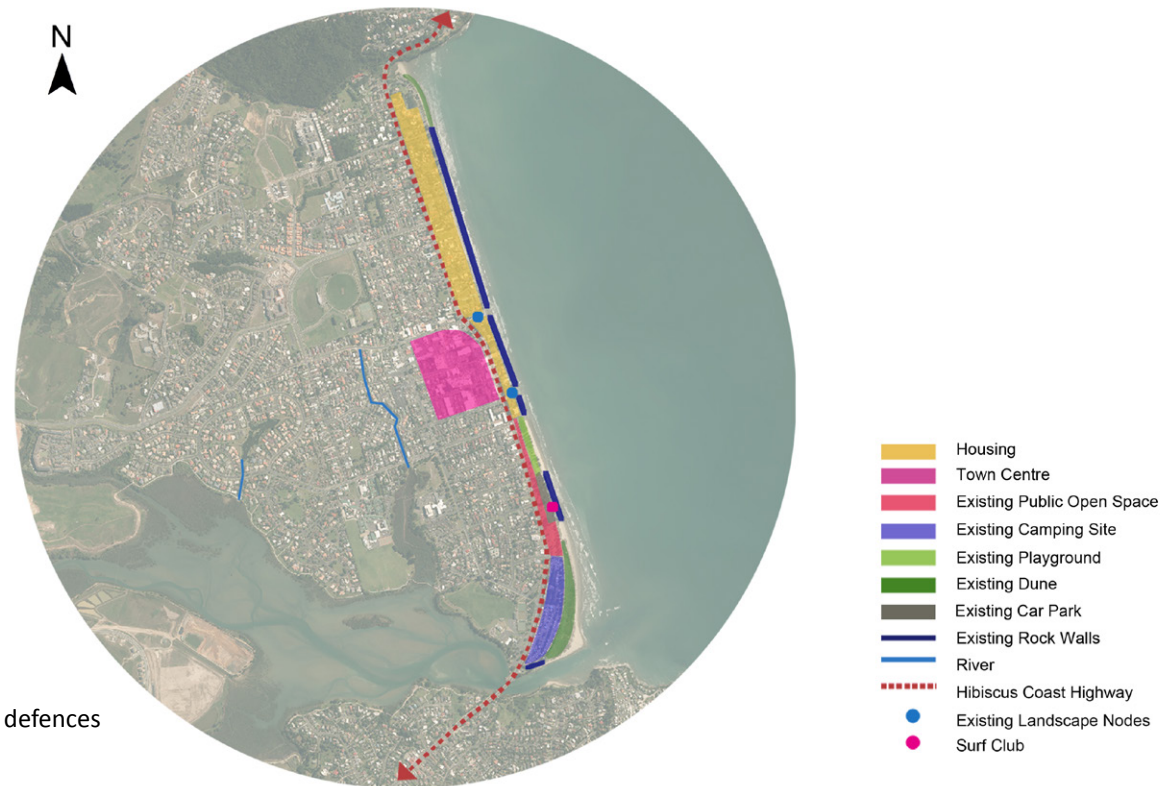


Figure 109. Existing protection defences

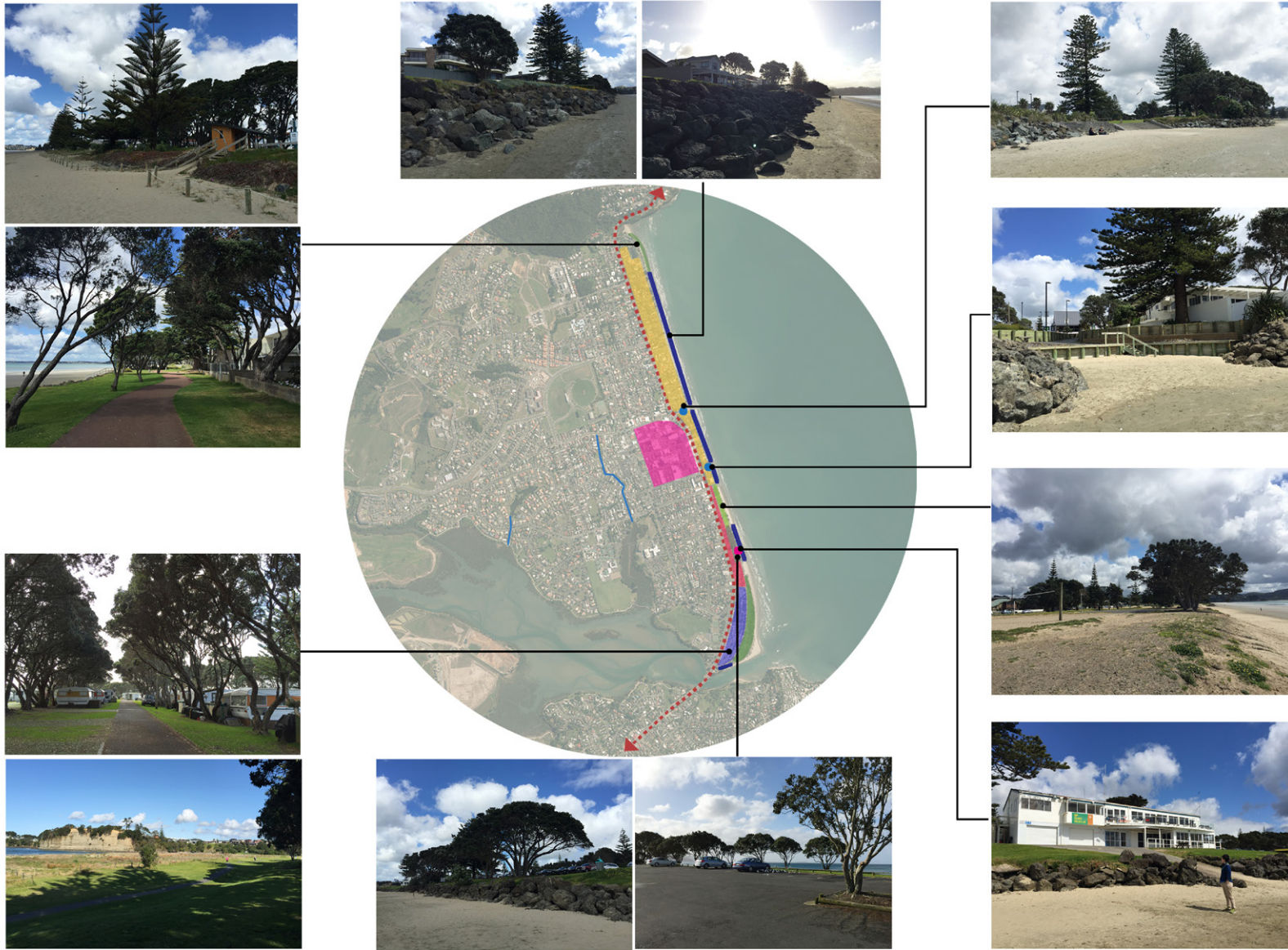


Figure 110. Site visits photographs

As seen in Figure 111, there are only two areas of dunes, with the majority of them at the southern end of the beach near the estuary mouth (Figure 113) and very little proportion in the northern end (Figure 112). One of my suggestions is to increase the size of the dune areas to resist wave energy. Based on the fact that there is nearly no dry beach currently during high tide, in the proposal, this dune construction work is carried out after increasing the beach width by installing artificial reef system.



Figure 111. Existing dune locations at Orewa Beach



Figure 112. Northern dunes at Orewa Beach (2015).



Figure 113. Southern dunes at Orewa Beach (2015).

5 Design Evolution

Adaptive Landscape Strategies
Design Evolution

5.1 Adaptive Landscape Strategies

The adaptive landscape strategies in my research are developed from adaptation approaches, compartmentalization and environmentally-friendly techniques. Adaptation approaches lay out the framework to respond to coastal hazards, while the compartmentalization concept provides an opportunity to increase the flexibility of the Orewa coastline as a whole through the combination of appropriate strategies (protection, accommodation or retreat) for individual compartments. Different environmentally-friendly techniques are developed, supporting each branch of different adaptation approaches, solving specific problems, such as there being no dry beach at high tide, high wave energy from storm surges, flooding, and having insufficient recreational spaces along the shore especially when sea level rises. These three parts constitute the adaptive landscape strategies in the project, contributing to rebuilding a resilient interface between the land and sea at Orewa for the long term.

5.1.1 Adaptation Approaches

The Intergovernmental Panel on Climate Change (IPCC) defined an international framework describing three approaches to coastal adaptation practices (IPCC CZMS 1990; Klein & Tol, 1997). To be specific, the adaptation approaches (Figure 114) are protection, accommodation and managed retreat. They are internationally recognised in academia as ways to address coastal hazards (such as coastal erosion and flooding).

A general description of these approaches follows. Protection involves defending vulnerable areas, especially population centres, economic activities and natural resources (Linham & Nicholls, 2010). It includes the ideas of holding the line and managed advance, preventing coastal erosion by introducing outside human forces. Accommodation focuses on an increased flexibility, by continue occupying vulnerable areas but with an acceptance of flooding changing the land use and/or construction to some extent (Linham & Nicholls, 2010). Managed retreat reduces vulnerability by abandoning currently developed areas. Inhabitants are relocated to safe locations, and new developments are required to be set back a safe distance from the coast (Linham & Nicholls, 2010).

Adaptation Approaches

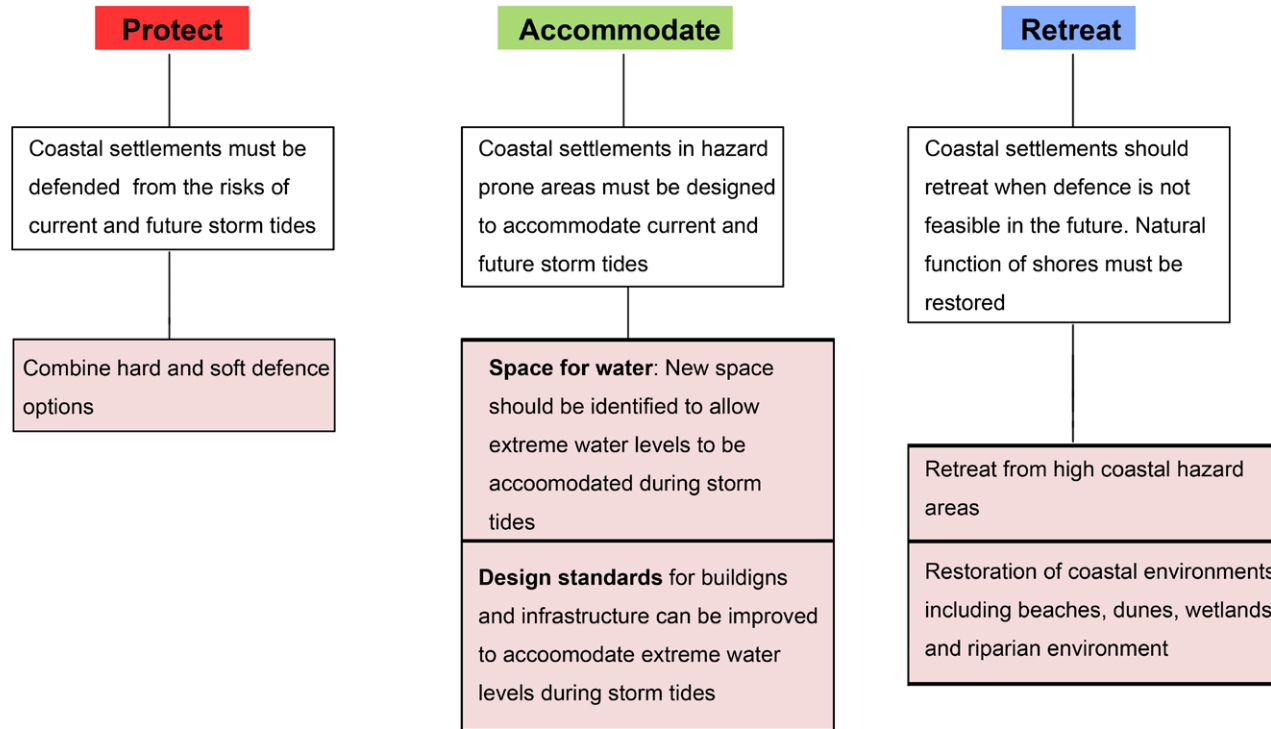


Figure 114. Adaptation Approach Framework

5.1.2 Compartmentalization

Based on the compartmentalization concept, the research site is split into several compartments according to their different land use features. Each compartment is analysed individually, considering its ecological and socio-economic characteristics. Then, corresponding approaches (protection, accommodation and managed retreat) are analysed and then selectively applied to each compartment. Finally, an integrated method is developed from the collection of different approaches.

5.1.3 Techniques

Different environmentally-friendly techniques are utilised under each adaptation approach to solve specific problems. As summarised in Figure 115, three main technologies (submerged artificial reefs, softened coastlines and dune rehabilitation) are adopted in the protection strategy; construction of the salt marsh is used as the main technique in the accommodation strategy; and in the managed retreat strategy, techniques including abandoning current developed areas and relocating the inhabitants to another safe areas.

Adaptation Approaches	Technologies	How It Works	Comments
Protection	Artificial Reef Balls	Building submerged artificial reefs	Reduce the wave energy and widen the beach width during high tide
	Dune Construction	Allowing sand dunes to build up around wooden structures	Dunes act as a buffer against the energy of waves and provide a sediment reservoir to replace eroded foreshore sediments
	Softened Coastline	Creating a soft green space up to a height instead of the original hard protection structures	Absorb most of the energy in storm surges, upgrade the look and enhance biodiversity
Accommodation	Salt Marsh Creation	Allowing the sea to enter hinterland to some extent, creating saltmarshes	New habitats are created and it reduces the risk of flooding along the coast
Retreat	Managed Retreat	Abandoning the existing sea defences and places and building new ones further inland, creating a saltmarsh which also floods in storm conditions	Lose some land, houses or businesses, but new habitats are created and flooding is reduced in other areas

Figure 115. Adaptive strategies and corresponding technologies

Design Evolution

First Design Iteration

5.2 Design Evolution



Figure 117. Compartmentalisation analysis- first design

5.2.1 First Design Iteration

- **Compartmentalisation Analysis**

From the existing land use, in Orewa coast, three distinct areas with different characteristics are identified. According to these different features, the coast is split into three compartments for individual analysis (Figure 117).

Area A is the large northern area of residential buildings, which occupy nearly half of the coast; Area B is the public open space with a playground, large car park and Orewa Surf Club; Area C contains a campsite and relatively large area of dunes near the Orewa Estuary mouth at the south end. There is a total of 157 lots in Area A, but up to 150 lots for residence use and only 7 lots are public open space. Orewa has some of the most expensive housing prices in Auckland. Because of the economic value in this compartment, the proposed adaptation approach for Area A is protection.



Figure 116. Design Scope



Figure 118. Integrated adaptation approaches- first design

Area B contains important public open spaces including recreational space, infrastructure and the Orewa Surf Club along the coastal edge. Orewa Surf Club has been serving the community since 1950. There are not many surf lifesaving clubs in Auckland, so the Orewa club is special. Recreational space provides a social place for the community. Additionally, these public open spaces are a vital buffer zone between the land and sea, protecting the inland from coastal hazards. Considering the important environmental, social and economic values of this compartment, the suggested adaptation approach for Area B is protection.

A popular campsite is located in the Orewa Reserve in Area C. For the consideration of the significance of natural reserve, protection approach is chosen for this area. A large area of dunes at the southeast end protect the majority of the natural reserve from storm surges, however, for the south end of the reserve near the Orewa Estuary, the only protection there currently is a rock wall, which has adverse effects on the coastal ecosystem. Considering that there is not enough space for dune planting to protect the area inland, I propose to take the accommodation approach in the area (marked with purple colour in Figure 119) near the estuary, change the land to a salt marsh there and remove the existing rock wall. During high tides and storm surges, sea water would be allowed to enter this newly created saltmarsh area. Hazards will be reduced in a resilient way. Consequently, the integrated adaptation approach for Area C is the combination of protection and accommodation.

By analysing each compartment, the initial integrated adaptation approaches selected for the Orewa coastline are protection and accommodation (Figure 118).

- **Corresponding Techniques**



In Area A, the existing erosion protection are the rock seawall in front of the buildings, which is the main intervention in this compartment, and the poor-management dunes at the north end of the beach. Wave reflection from seawalls often worsens loss of sediment from beaches. Due to its adverse effect on the coastal ecosystem, one of the suggestions is to replace the rock seawall with a softened coastline. These new sloping green spaces are expected to absorb most of the wave energy in extreme weather conditions, mitigating the effect of sea level rise to a large extent. They will also upgrade the coastal look and create opportunities to enhance biodiversity. Another technique used in this segment is the construction of dunes in front of the sloping green space near the sea. Large stretches of dunes can protect this area from storm surges, trapping sand on the beach and providing habitats for a variety of plants and animals. The prerequisite for dune building is the existence of a wide sandy beach, which is also a key stage in this project. The suggested technique for widening the beach is to install submerged artificial reefs. Waves are dissipated by these submerged defences before they reach the coast, and sand is naturally accumulated along the shore. Another problem is the stormwater outlets located on the beach. Sand is eroded when stormwater is discharged directly to the beach through these drains. My suggestion is to design a bio-swale strip and stormwater wetlands to reduce the effects from stormwater outlets. The proposed bio-swale strip, marked in green in Figure 119, is on the Hibiscus Coast Highway between Moana Ave and in front of Northbridge CI near the coast side. The stormwater wetlands are designed in front of coastal buildings, replacing some sections of the stormwater outlets.

Figure 119. Bio-swale design scope

In Area B, the only existing protection is a rock seawall in front of the car park. The playground in this area suffers from severe coastal erosion, as it has no protective defence. My suggestion is to upgrade the recreational area in front of the playground. The proposed design combines ecological steps and a terraced wooden platform to reduce wave-induced erosion and provide a more flexible recreation area when sea level rises. In addition, the newly designed tidal swimming pool near the Orewa Surf Club on the beach will enrich the types of water sports. Other techniques include construction of submerged artificial reefs and dunes for erosion-reduction purposes.

There are four major suggestions in Area C (Figure 120). Firstly, the south end of dune protection is relatively ideal, however, the area between the top of existing south end dunes and the bottom of existing car park are without any protection, making this area vulnerable to coastal erosion. I suggest to extend the area of existing dunes to the bottom of the car park, increasing this area's ability to resist storm surges. Secondly, construction of submerged artificial reefs (marked with brown colour) are also suggested. The artificial reef on the top right is designed to help sand accumulate along the shore in Area C, and the one in the estuary mouth is designed to recover the original sand transport circulation by imitating the shape of the Waitemata Reef. Thirdly, the current high tide mark is already almost on the edge of the existing rock seawall (south end). According to ARC (2006), the projection of "likely" erosion width is 13 m and "possible" erosion width is 28 m at Orewa Beach over the next 100 years. That means that part of the south end campsite will be inundated by the sea. However, there is not enough space to install dune protection, so my suggestion is to use the accommodation strategy here, allowing seawater to enter the area to some extent, forming a natural saltmarsh that can absorb rising sea levels and trap sand for the shore. This newly created saltmarsh will also be integrated in the adjacent mangrove forest, which already exists, enhancing biodiversity in Orewa. Fourthly, two wooden bridges are proposed with different aims. The one crossing the new saltmarsh has the purpose of strengthening the

bonds between the two communities. People from the adjacent Red Beach can come to Orewa Beach via this wooden bridge in a more convenient way. The other one would be constructed to provide a recreational function to improve tourism. Taking the tidal range into consideration, a floating deck was designed. People can cross the bridge to enjoy diving activities around the newly created Waitemata Artificial Reefs.



Figure 120. Proposed techniques in Area C

Big Idea

Four protective buffer zones are integrated as a holistic adaptive system is the big idea in the research project, seen in Figure 121. The Artificial Reef Buffer Zone is the first system in the sea, which provides protection from erosion by reducing wave energy. The Dune Buffer Zone is the second protection system to resist storm surges and act as a sediment reservoir. The third protection system called the Green Space Buffer Zone, is located behind the Dune Buffer Zone. It is an important natural protective system to protect the behind houses and infrastructure and is expected to resist future sea-level rise. Fourth, the “Bio-swale Zone” works as the supporting system for the other three systems by reducing stormwater run-off from the inland urban areas before it reaches the outlets on the beach, thereby reducing erosion. The four systems will work together to reach the goal of mitigating coastal erosion at Orewa.

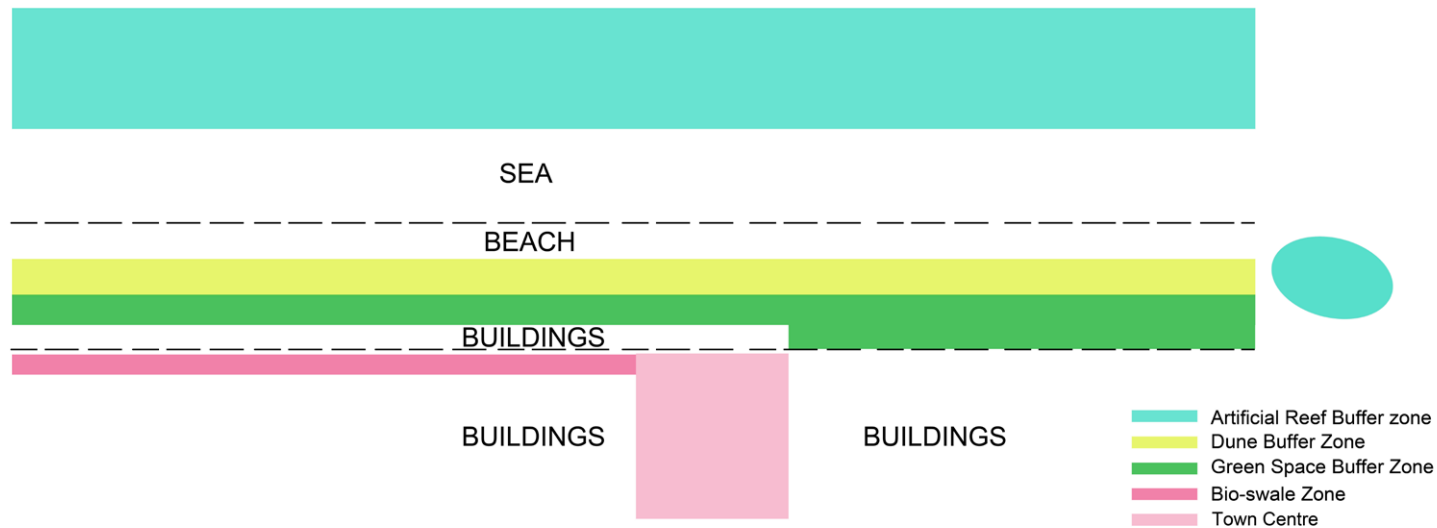


Figure 121. Adaptive Buffer Zones - First Design

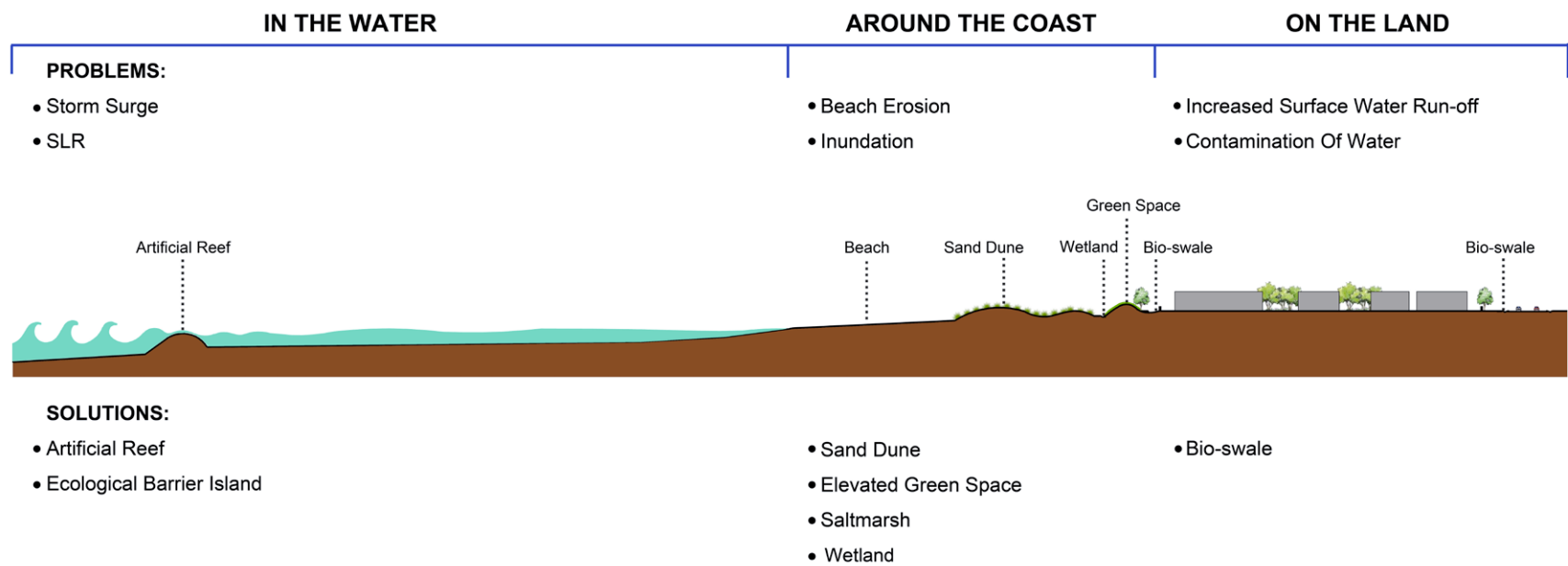


Figure 122. Integrated Buffer System Section

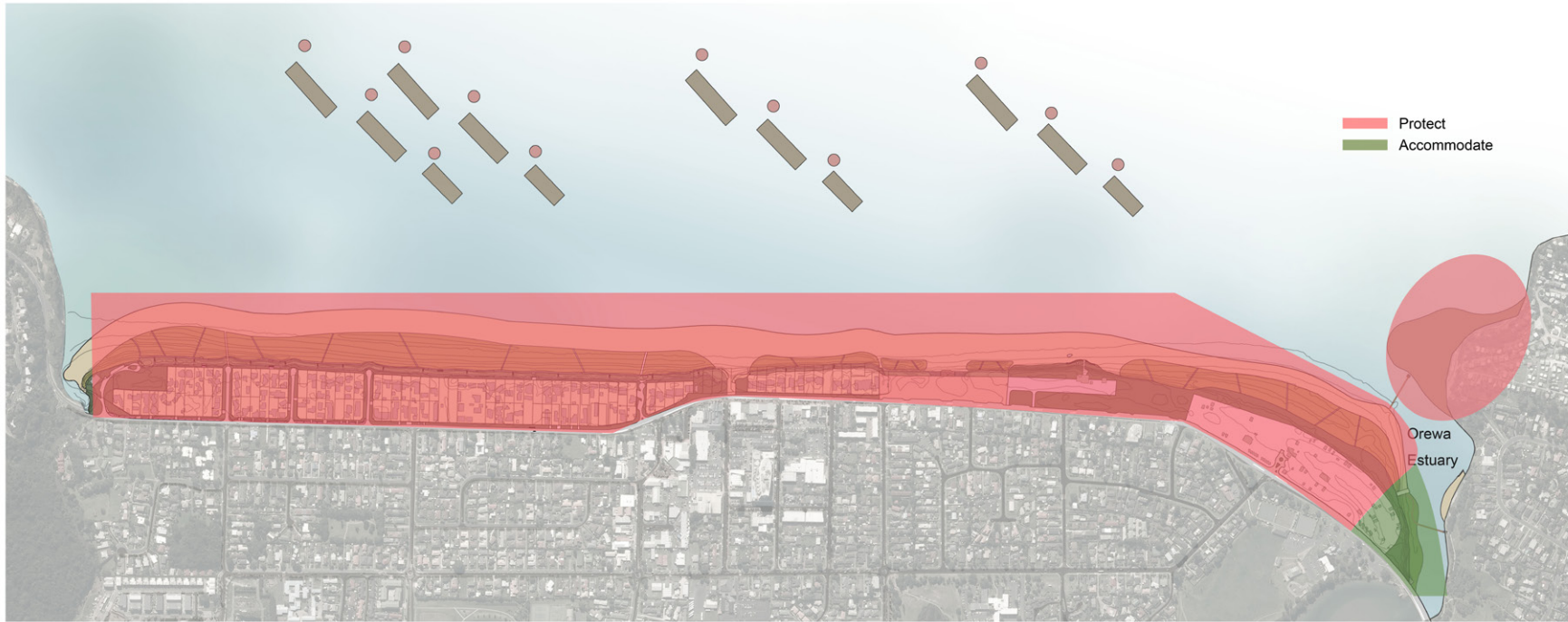


Figure 123. Adaptation strategies - First Design

- **Phased Strategies**

As seen in Figure 124, during stage one, the submerged artificial reefs are installed and the Artificial Waitemata Reef is constructed by simulating its original shape. By doing so, wave energy will be largely reduced by these submerged structures before waves reach the shoreline, and the natural sand transport will be recovered. During stage two, sand is accumulated in the lee of the artificial reef, and then in stage three, sand is relocated along the shore by natural forces (longshore drift and estuary currents). After the beach is widened in stage four, building large area of dunes along the shore to protect the fragile inland from storm surges. In stage five, a sloping green space will be constructed to resist higher wave energy. A saltmarsh will be created in stage six followed by building two wooden bridges in stage seven.

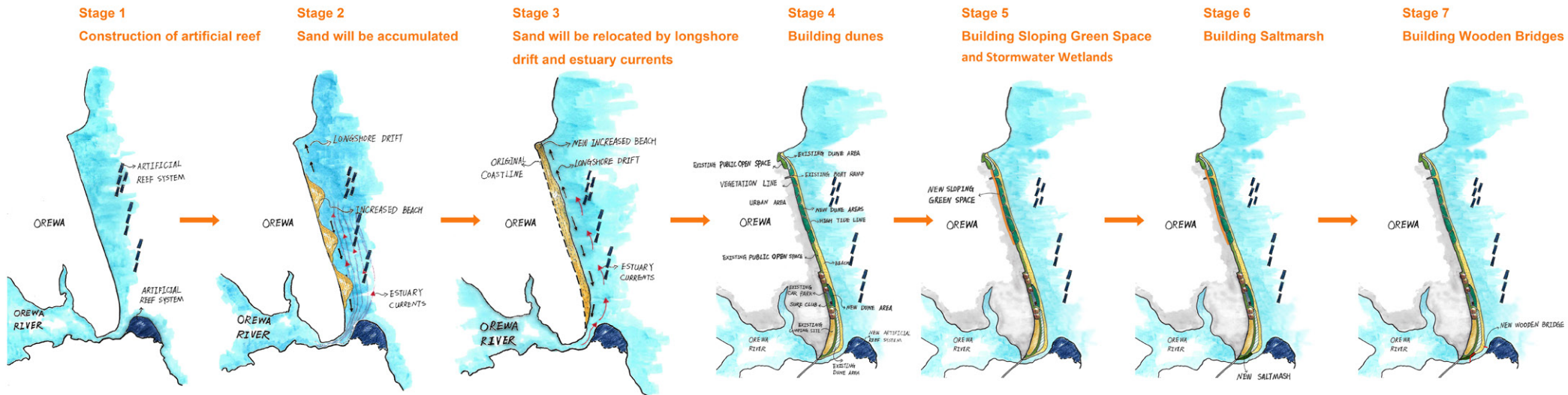
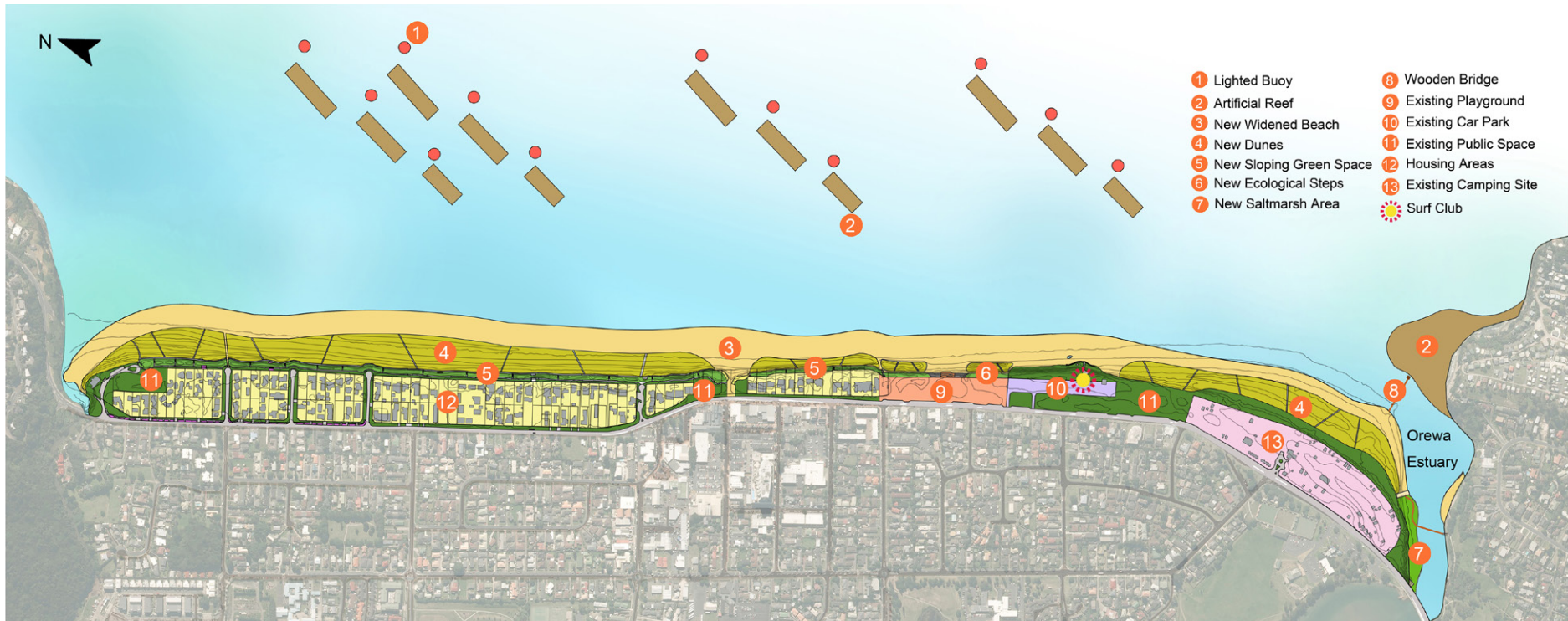


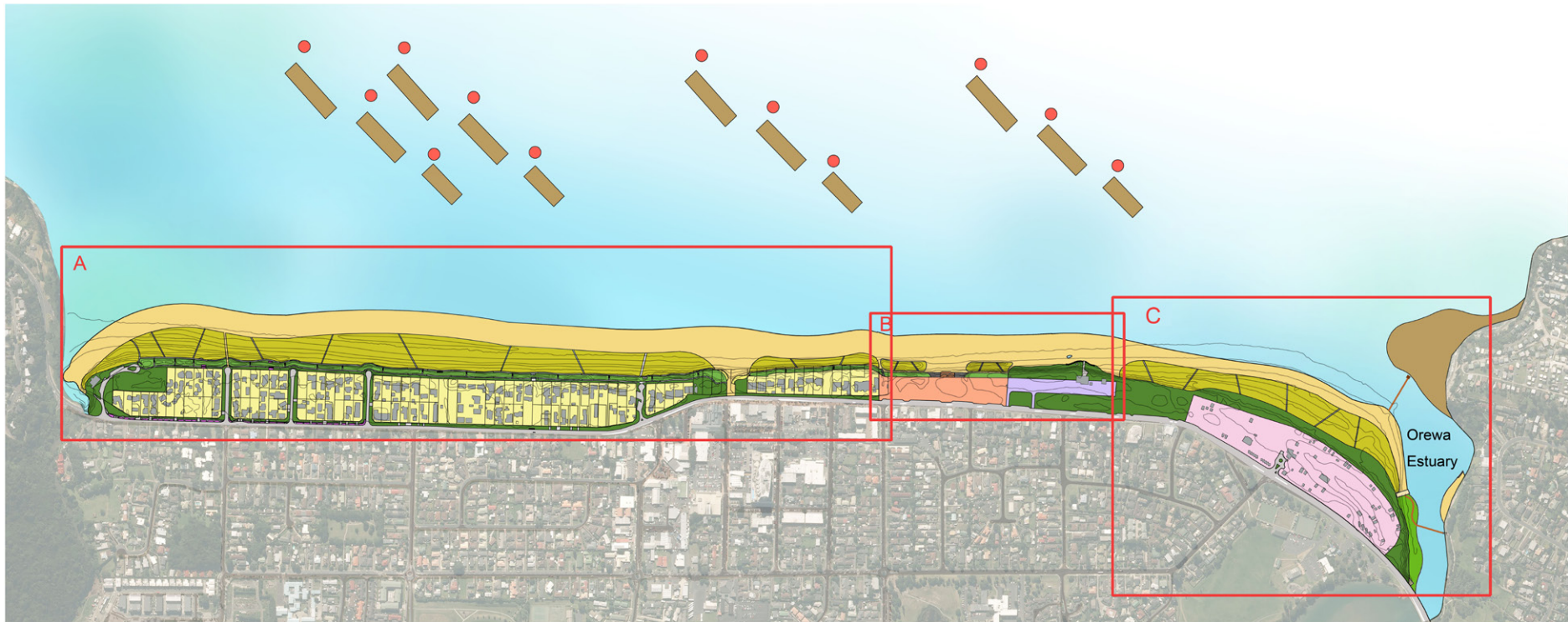
Figure 124. Phased Stages - First Design

- **First Design Iteration**

The initial Master Plan is developed after the previous analysis. In the design, a widened beach, dunes, saltmarsh, wooden bridges, cycleway, tidal swimming pool and sloping green space in front of the housing area and playground are created.



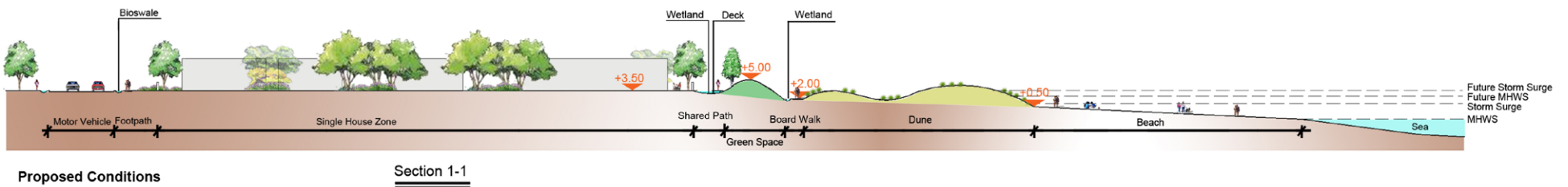
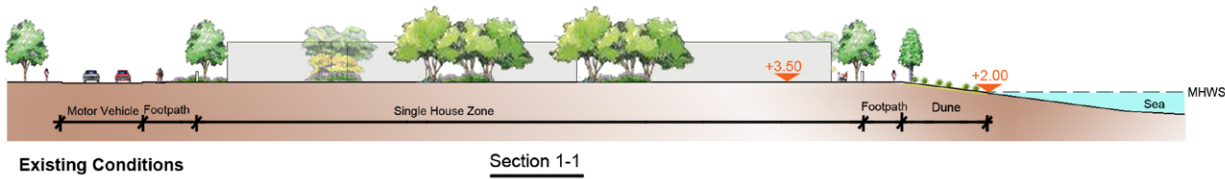
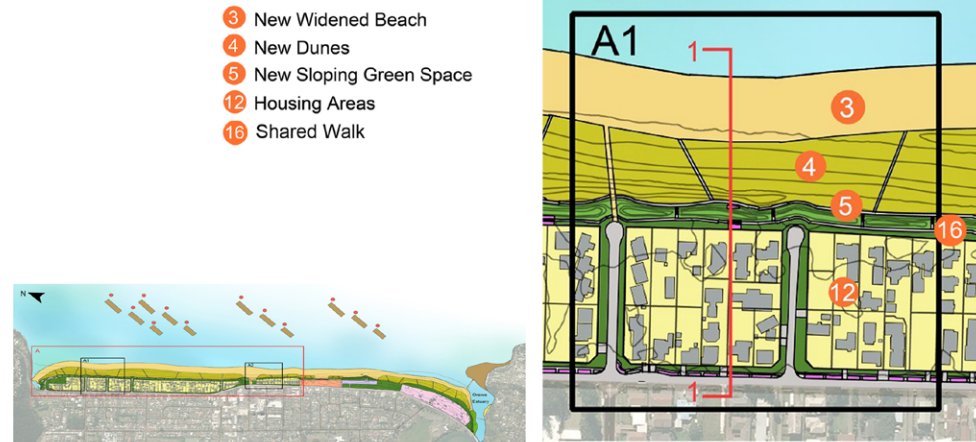
Master Plan - First Design



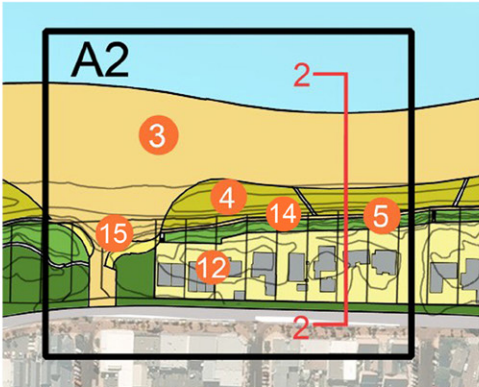
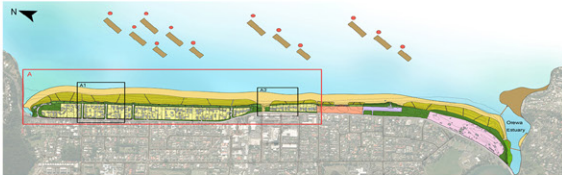
Zones - First Design

Sections – Area A1 (First Design)

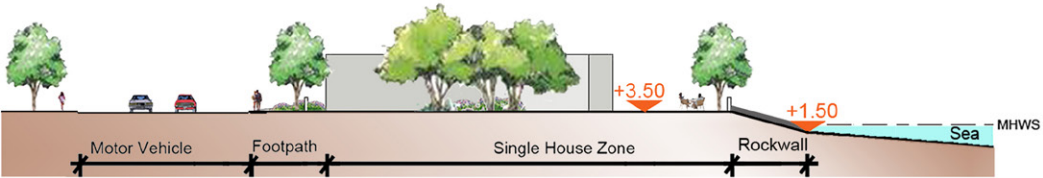
The peak elevation of the sloping green space is only 1.5 m higher than the nearby ground of buildings, so it will not block the sight while playing the role of resisting the future sea level rise.



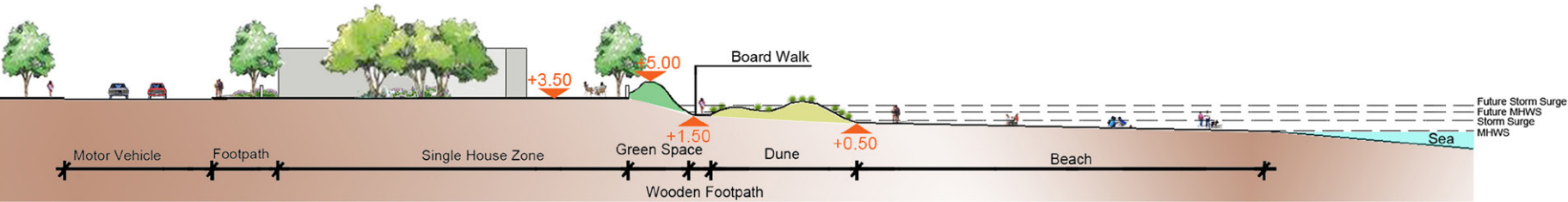
Sections – Area A2 (First Design)



- 3 New Widened Beach
- 4 New Dunes
- 5 New Sloping Green Space
- 12 Housing Areas
- 14 New Board Walk
- 15 Existing Entrance Plaza



Existing Conditions Section 2-2

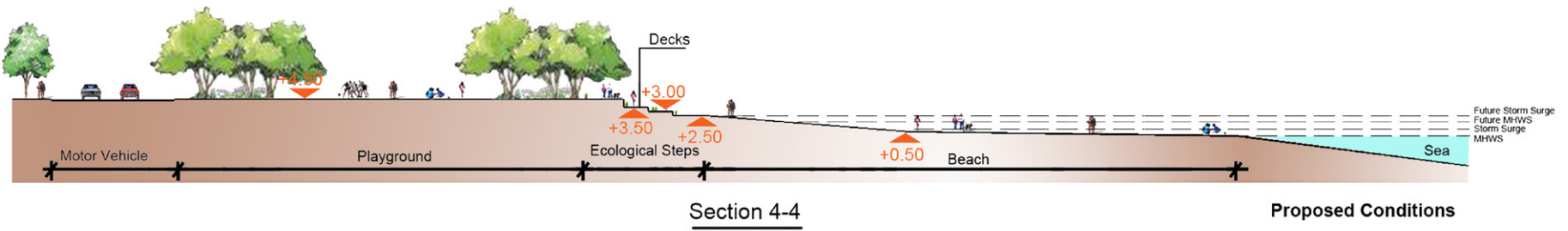
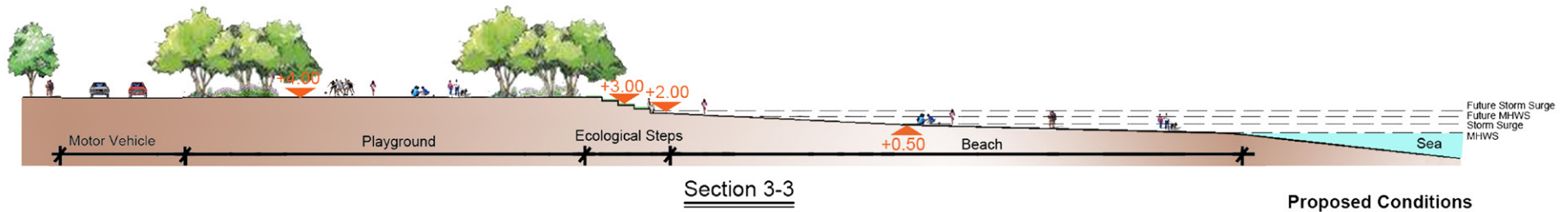
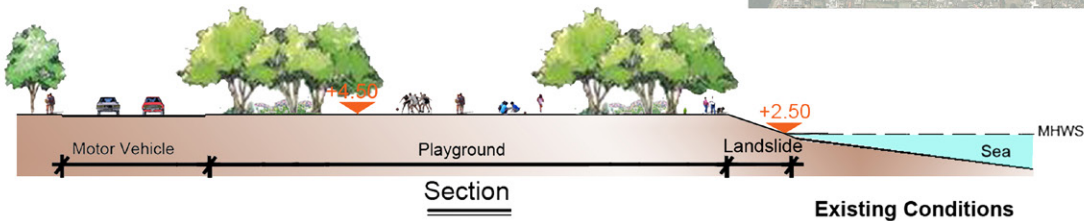
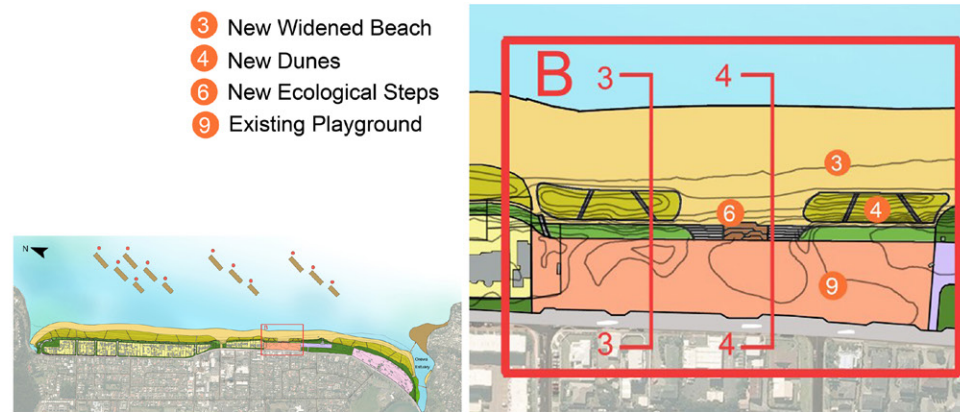


Proposed Conditions Section 2-2

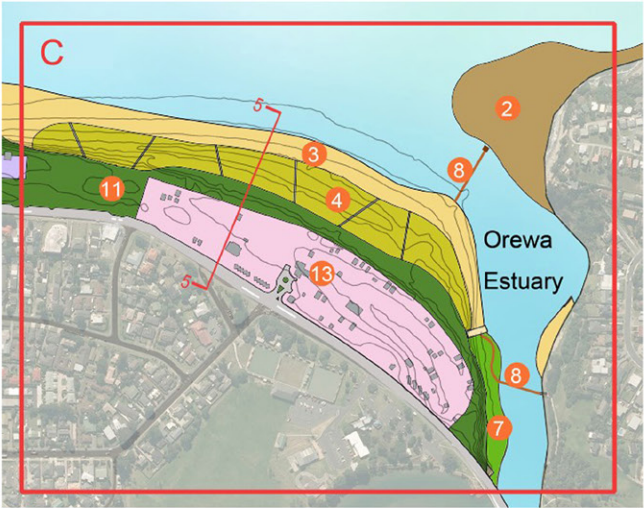
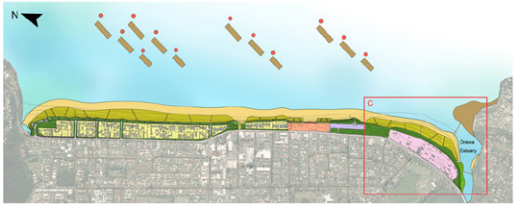
Sections – Area B (First Design)

The proposed ecological steps and terraced wooden platform can reduce wave-induced erosion while providing a more flexible recreation area for people to use when sea levels rise in the future.

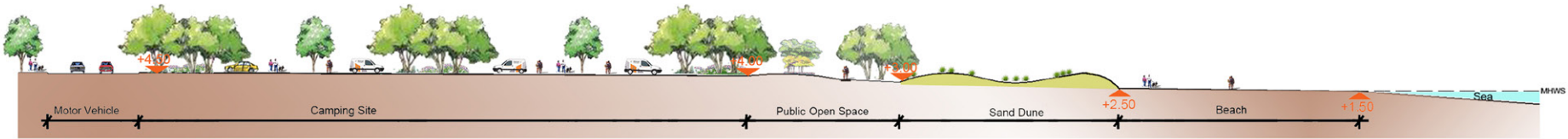
- 3 New Widened Beach
- 4 New Dunes
- 6 New Ecological Steps
- 9 Existing Playground



Sections – Area C (First Design)

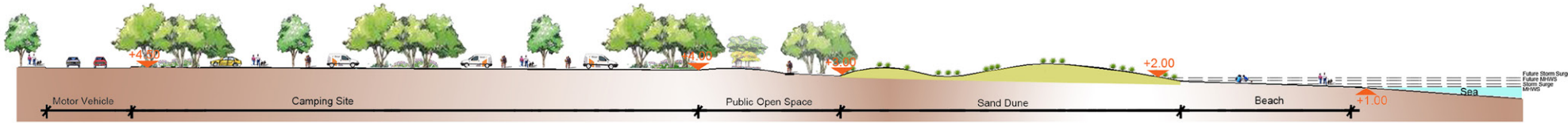


- 2 Artificial Reef
- 3 New Widened Beach
- 4 New Dunes
- 7 New Saltmarsh Area
- 8 Wooden Bridge
- 11 Existing Public Space
- 13 Existing Camping Site



Existing Conditions

Section 5-5



Proposed Conditions

Section 5-5

Design Evolution

Second Design Iteration

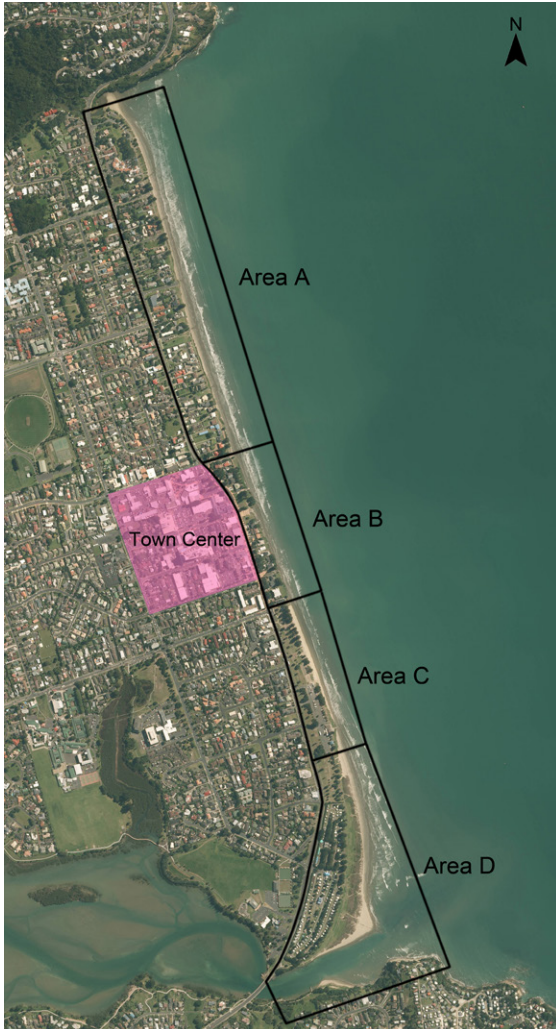


Figure 125. Compartmentalisation analysis- second design

5.2.2 Second Design Iteration

• Compartmentalisation Analysis

Orewa is a famous tourism town and attracts numbers of people every year for its amazing scenery and abundant activities. After reconsidering the special tourism features of Orewa, the original Area A is subdivided into two compartments. As a result, the coast is split into four compartments for individual analysis (Figure 125). Area A contains the large area of residential buildings in the north; Area B is the area in front of the town centre; Area C is the public open space with a playground, major car park and the Orewa Surf Club; Area D includes a campsite and relatively large area of dunes near the Orewa Estuary mouth in the south end. There are no changes to Area C and D from the initial proposition.

In Area A, a large number of buildings are included in the compartment. Due to economic considerations, the proposed adaptation approach for Area A is still protection. In Area B, there are 17 residential lots. Many buildings are situated in front of the town centre, blocking views and degrading the tourism value. My suggestion is to change the land use in front of the town centre along the shore from residential use to public open space. Consequently, the adaptation approach for Area B is managed retreat. The proposed adaptation approach for Area C is also protection, and an integrated option for Area D is still the combination



Figure 126. Integrated adaptation approaches- second design

of protection and accommodation. The second proposition of integrated adaptation approaches for Orewa is the combination of protection, accommodation and managed retreat, as seen in Figure 126.

- **Corresponding Techniques**

The techniques used for Areas A, C and D are the same as the initial proposition, the only change is in Area B. In Area B, nearly 20 houses will retreat from this compartment and replaced by a coastal park with abundant facilities. In addition to the recreational value, this park will reduce stormwater runoff to the coast as well and protect the inland town centre from coastal hazards. Another highlight is the proposed multi-functional boardwalk. The design of a terraced boardwalk with local coastal plants takes the existing elevation into consideration, providing more activity places when sea level rise and upgrading the tourism identity by its modern design.

Big Idea

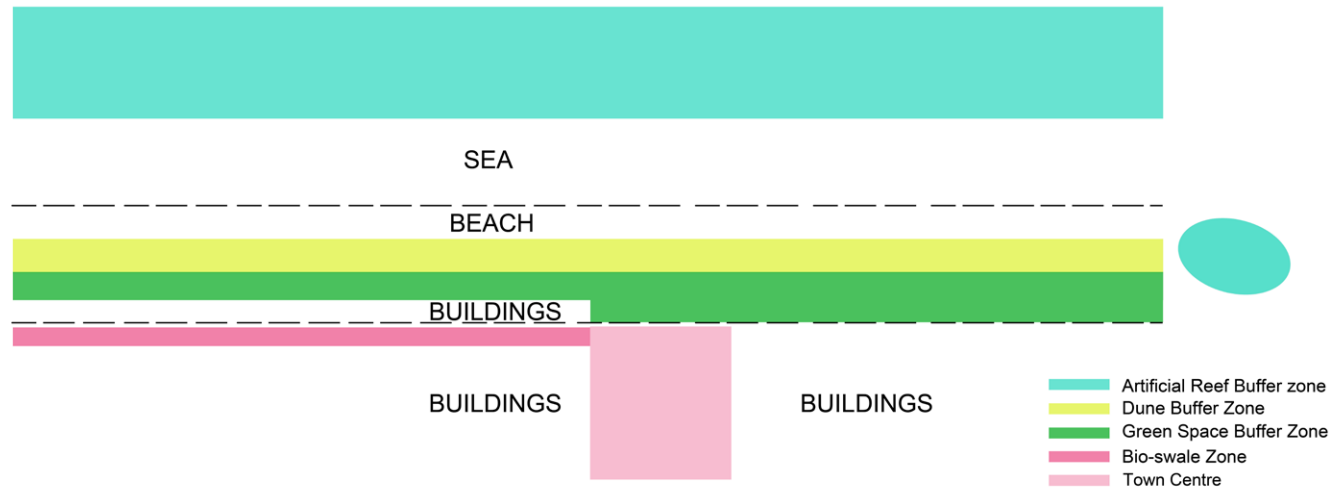


Figure 127. Adaptive Buffer Zones- Second Design

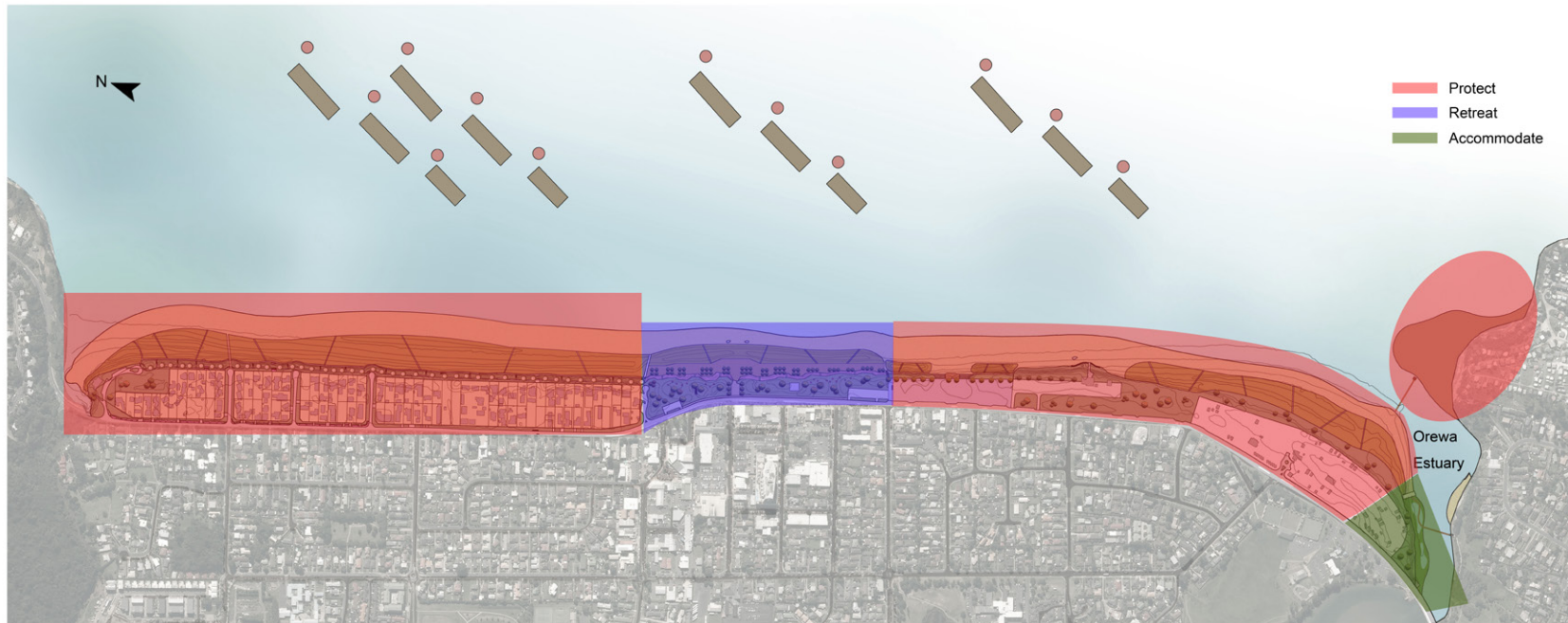


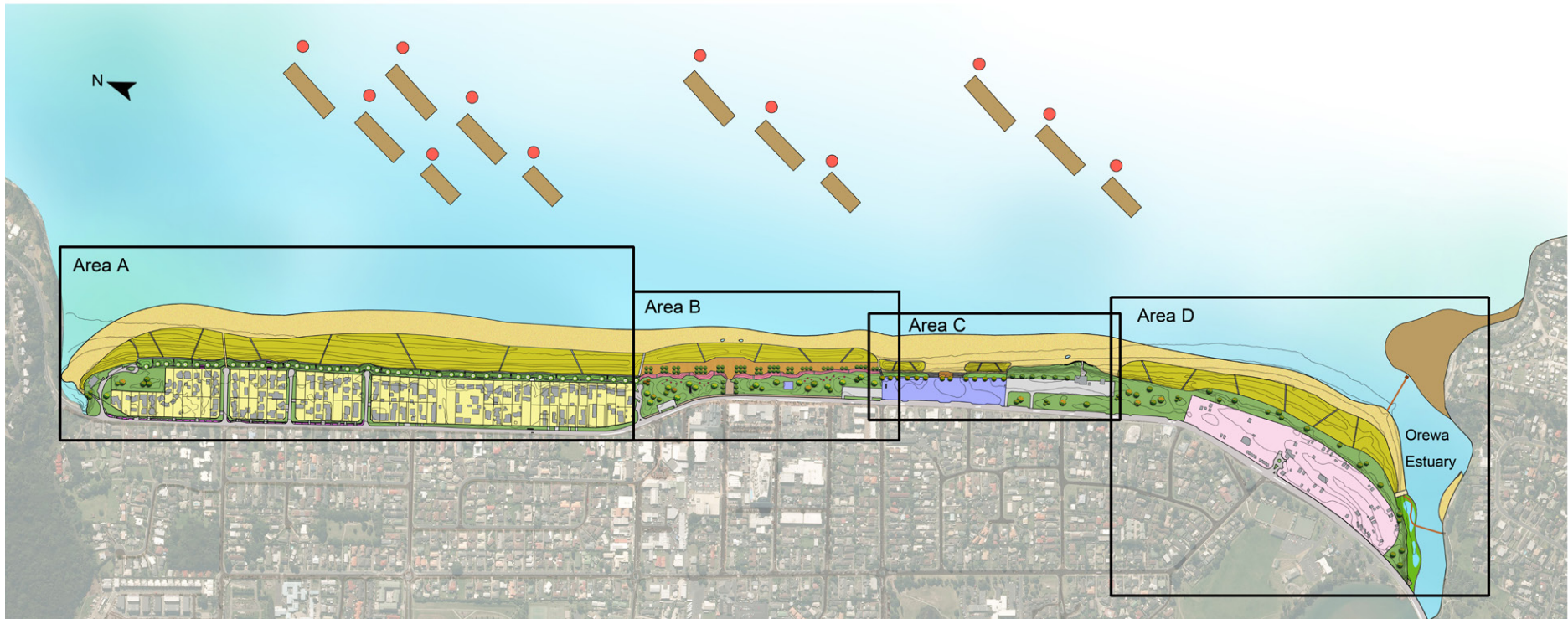
Figure 128. Adaptive Strategies - Second Design

- **Second Design Iteration**

Based on the initial master plan, a coastal park and multi-functional boardwalk are proposed in the second proposition.

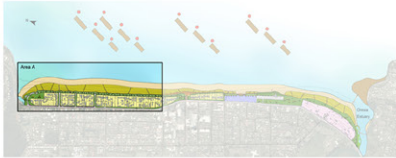
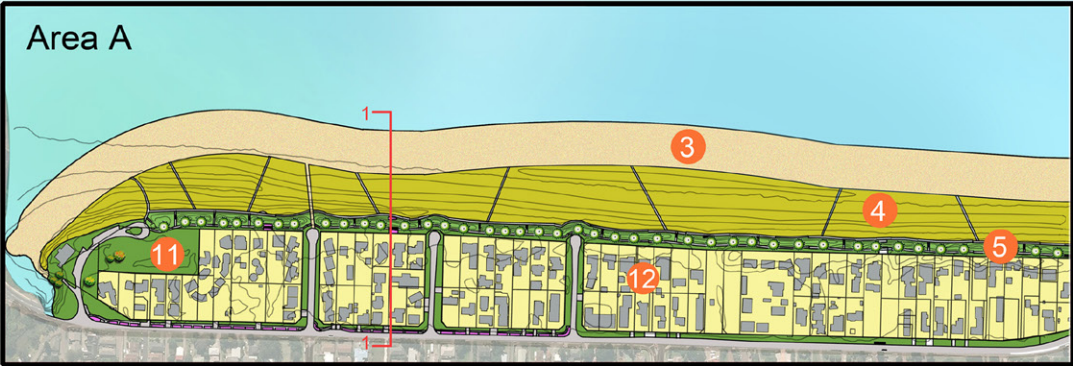


Master Plan - Second Design



Zones - Second Design

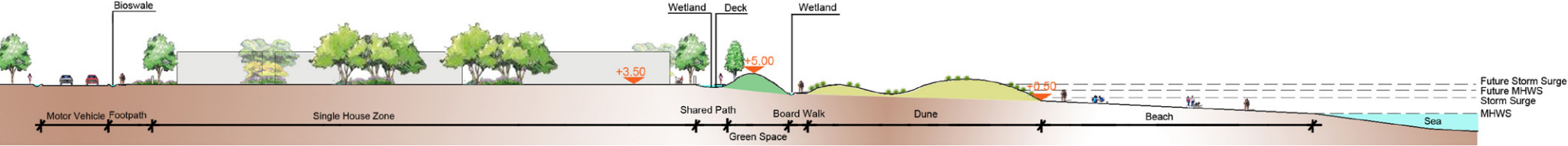
Sections – Area A (Second Design)



- 3 New Widened Beach
- 4 New Dunes
- 5 New Sloping Green Space
- 11 Existing Public Space
- 12 Housing Areas

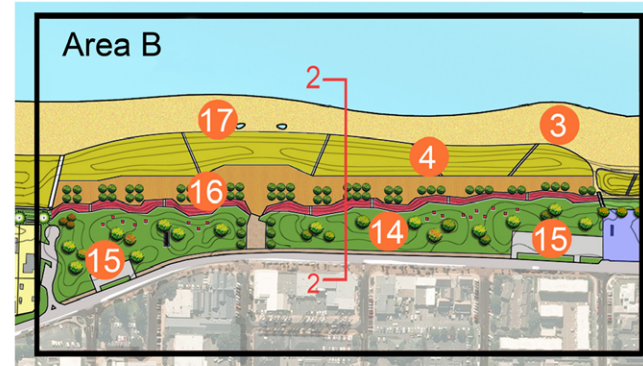
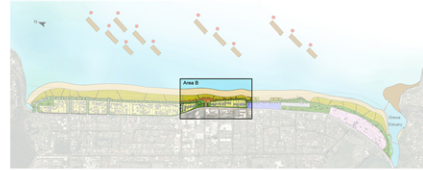


Existing Conditions Section 1-1



Proposed Conditions Section 1-1

Sections – Area B (Second Design)

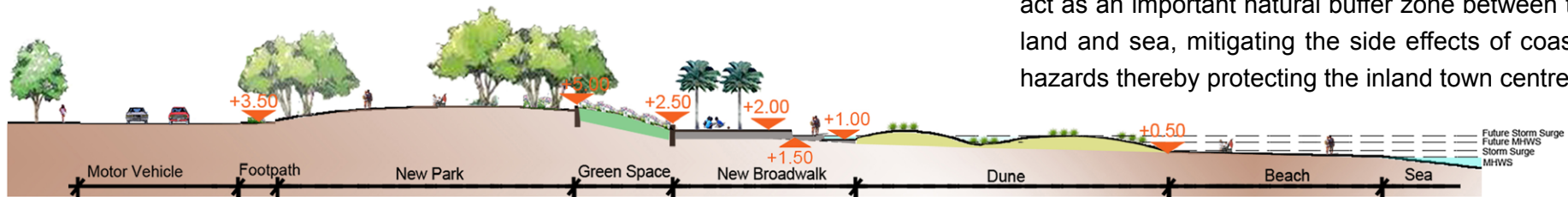


- 3 New Widened Beach
- 4 New Dunes
- 14 New Park
- 15 New Car Park
- 16 New Boardwalk
- 17 Tide Swimming Pool



Existing Conditions

Section 2-2

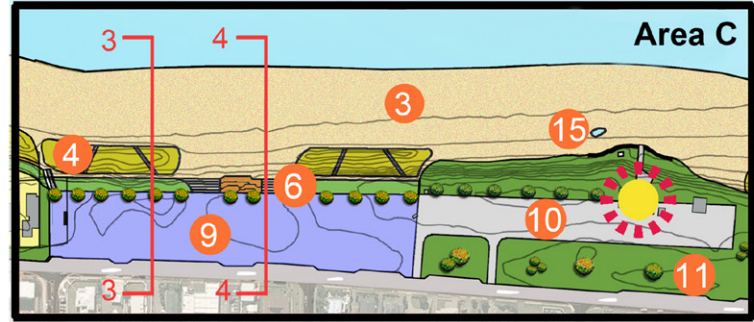
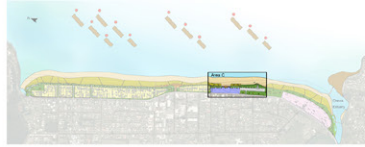


Proposed Conditions

Section 2-2

The proposed coastal park has abundant facilities such as a car park, playground, skate park, cycleway and BBQ areas. This park will break the current sight blocks caused by existing buildings, provide better sea views and easy public beach access. More visitors will be attracted to the beach, and its value as a holiday destination will be greatly enhanced. This new public open space can also act as an important natural buffer zone between the land and sea, mitigating the side effects of coastal hazards thereby protecting the inland town centre.

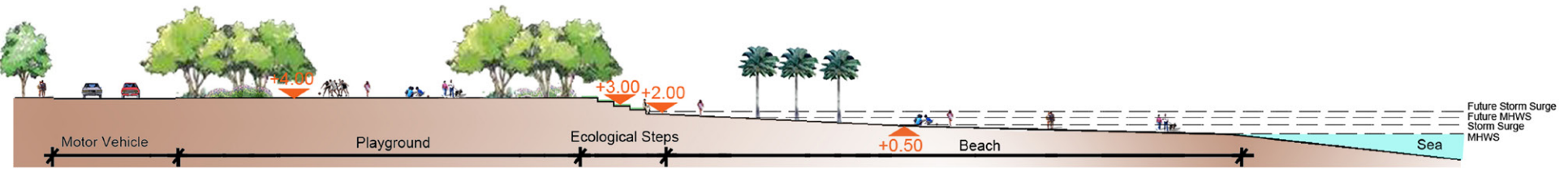
Sections – Area C (Second Design)



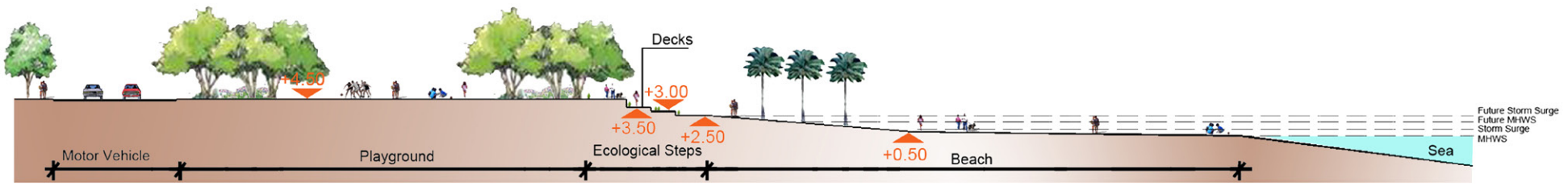
- 3 New Widened Beach
- 4 New Dunes
- 6 New Ecological Steps
- 9 Existing Playground
- 10 Existing Car Park
- 11 Existing Public Space
- 15 New Car Park
- 17 Tide Swimming Pool



Existing Conditions Section

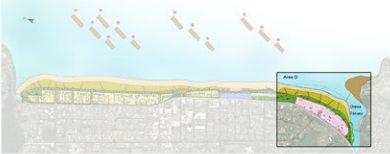
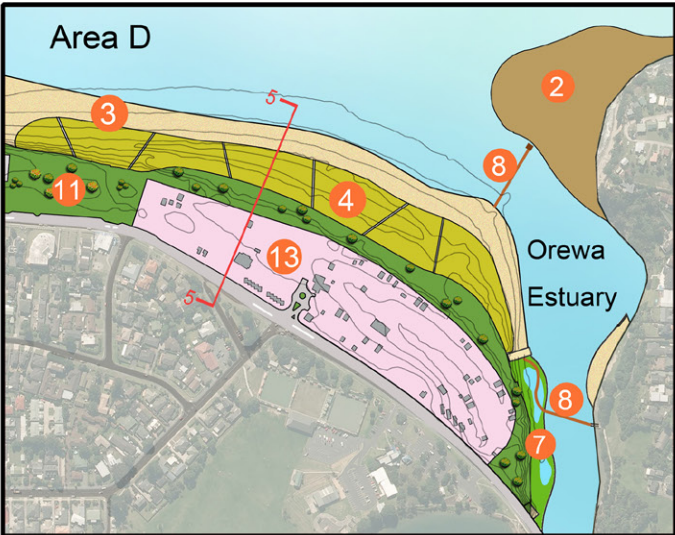


Proposed Conditions Section 3-3

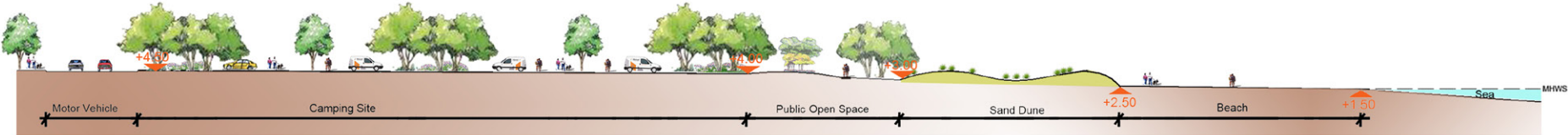


Proposed Conditions Section 4-4

Sections – Area D (Second Design)

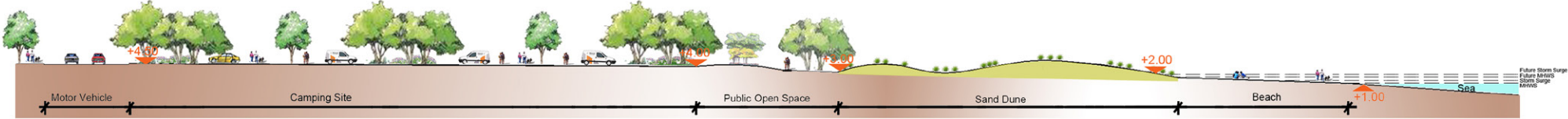


- 2 Artificial Reef
- 3 New Widened Beach
- 4 New Dunes
- 7 New Saltmarsh Area
- 8 Wooden Bridge
- 11 Existing Public Space
- 13 Existing Camping Site



Existing Conditions

Section 5-5



Proposed Conditions

Section 5-5

Design Evolution

Final Proposition

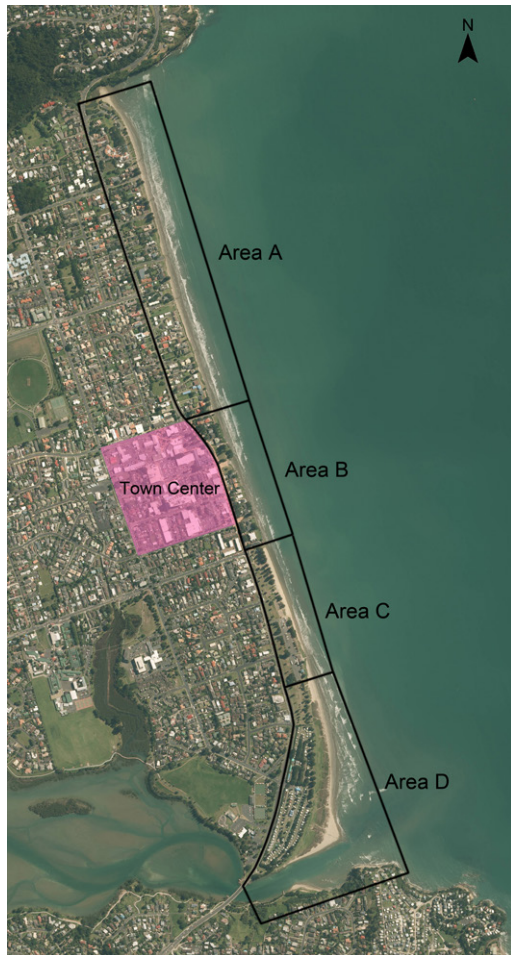


Figure 129. Compartmentalisation analysis - final proposition



Figure 130. Integrated adaptation approaches - final proposition

5.3.3 Final Proposition

- **Compartmentalisation Analysis**

The criteria for comparting the site is still the different land use and there are also four segments, seen in Figure 129. The only change of consideration is for Area B. Although there are some advantages to retreat these buildings in front of the town centre, but the cost will be too giant. According to GIS analysis (Figure 131), these buildings will be completely under the sea when sea levels rise by 2 m, but they will be relatively safe in the next 100 years (considering sea level rise of 1 m). Thus, the strategy for Area B, for at least for the next 100 years, is protection. The final proposition of integrated adaptation approaches for Orewa is the combination of protection and accommodation, as seen in Figure 130.

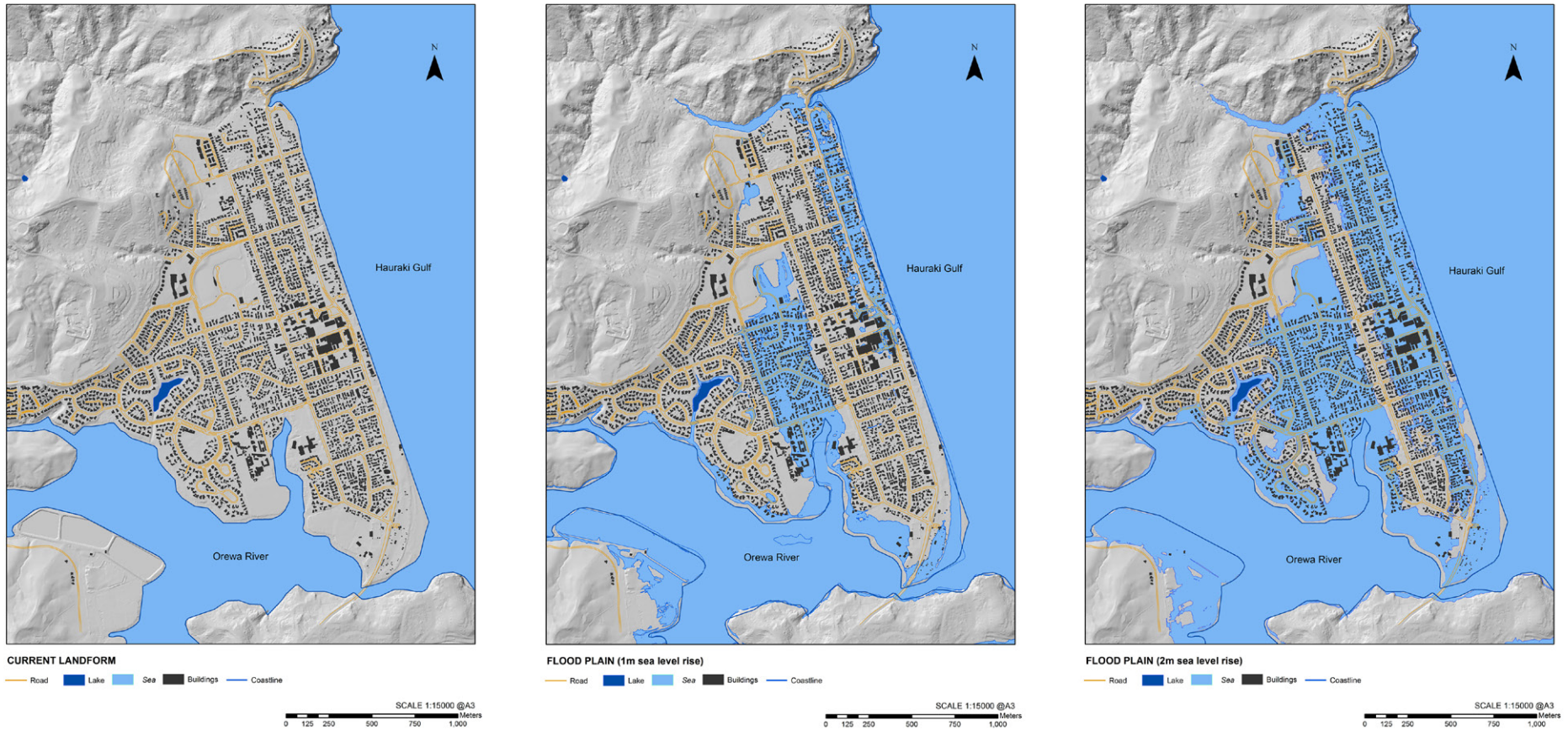


Figure 131. Changes of landforms due to sea-level rise (0m-1m-2m)

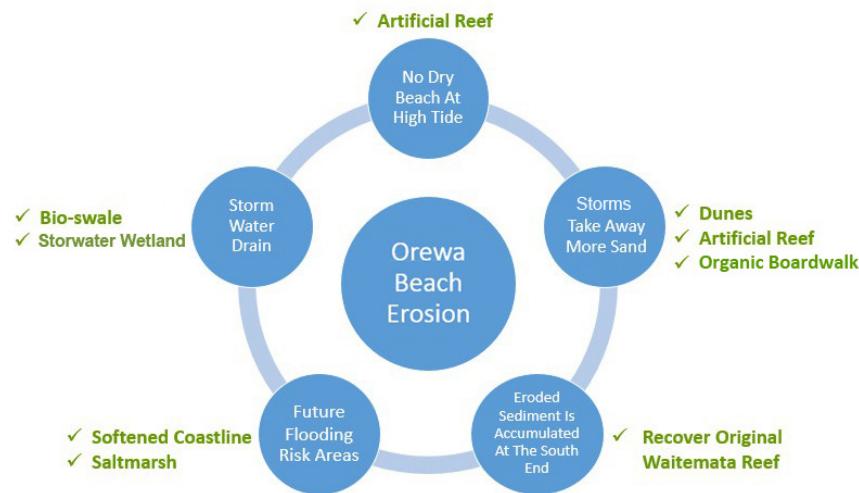


Figure 132. Techniques responding to different problems

• Corresponding Techniques

Compared to the second proposition, the only change is in Area B. According to ARC (2006), the likely erosion width for Orewa will be 13 m with a possible erosion width of 28 m. That means almost all of the buildings in Orewa will be at a risk of collapse if no actions are taken. Under this circumstance, the combination of sloping green space, an organic boardwalk and dunes are proposed. This new organic boardwalk can trap more sand for building dunes. Figure 116 shows the five different problems causing beach erosion at Orewa Beach and corresponding solutions to each problem.

Big Idea

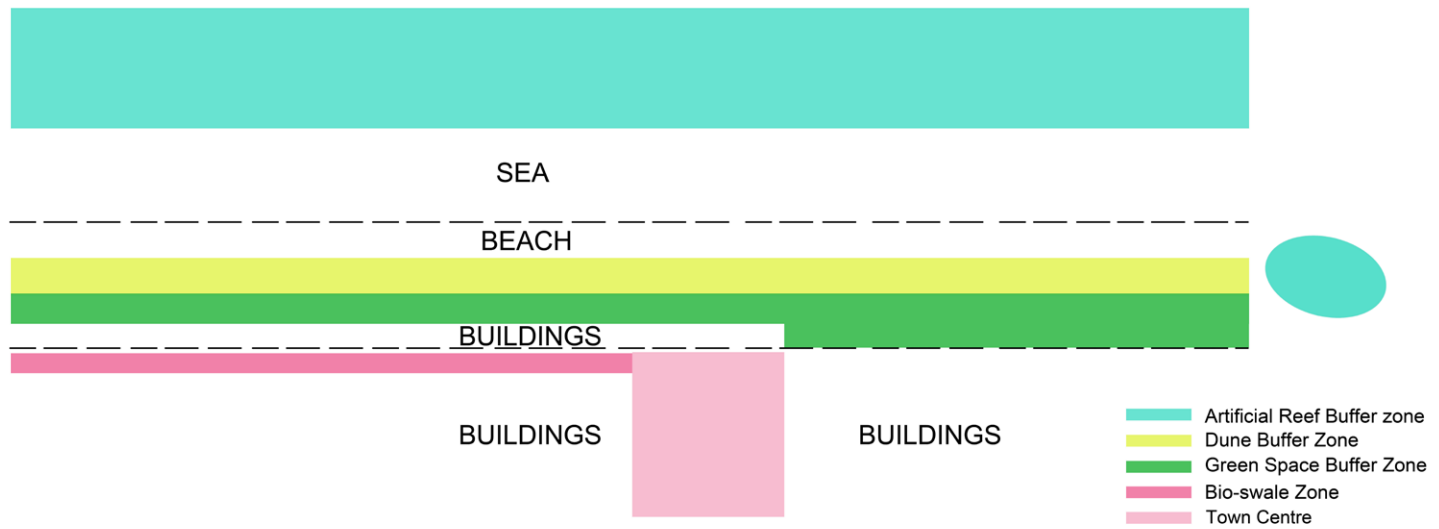


Figure 133. Adaptive Buffer Zones- Final Proposition

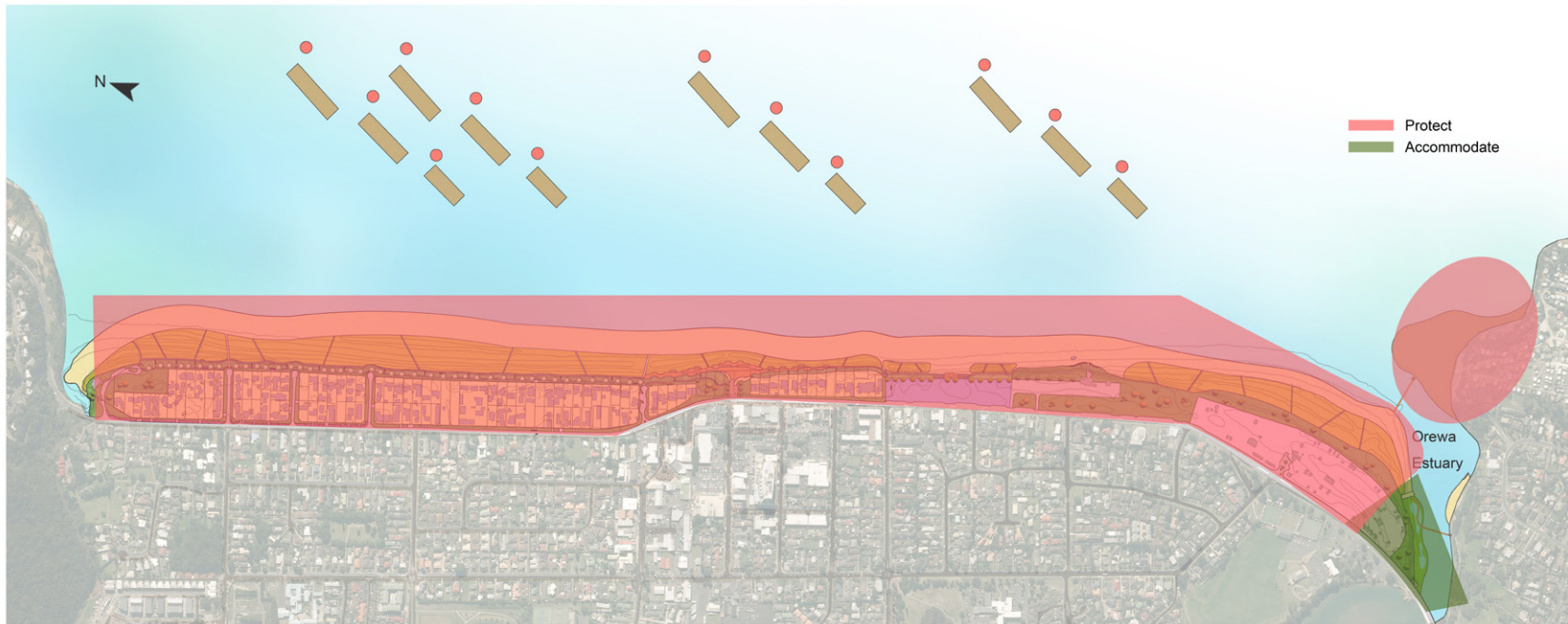


Figure 134. Adaptive Strategies - Final Proposition

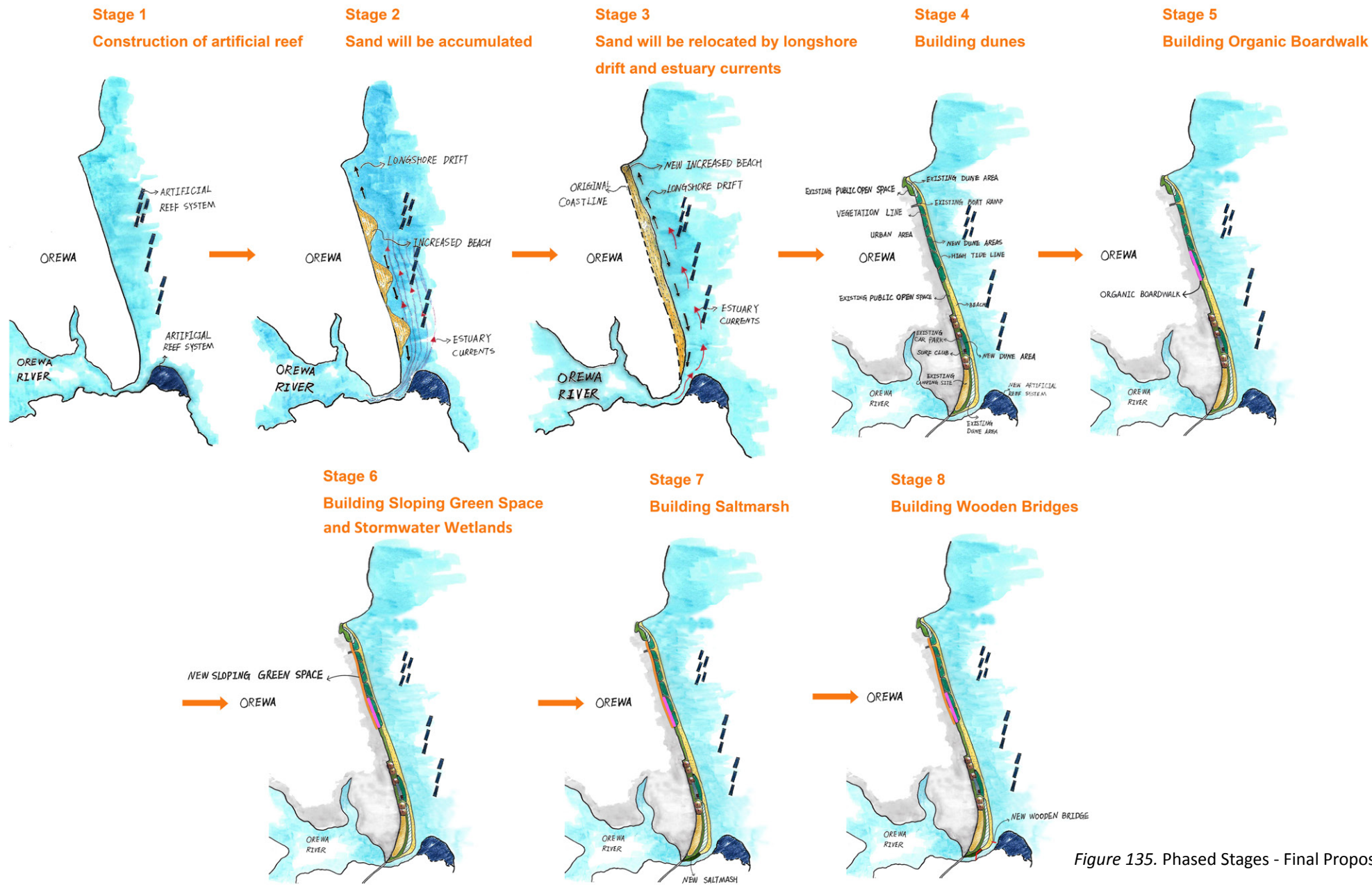
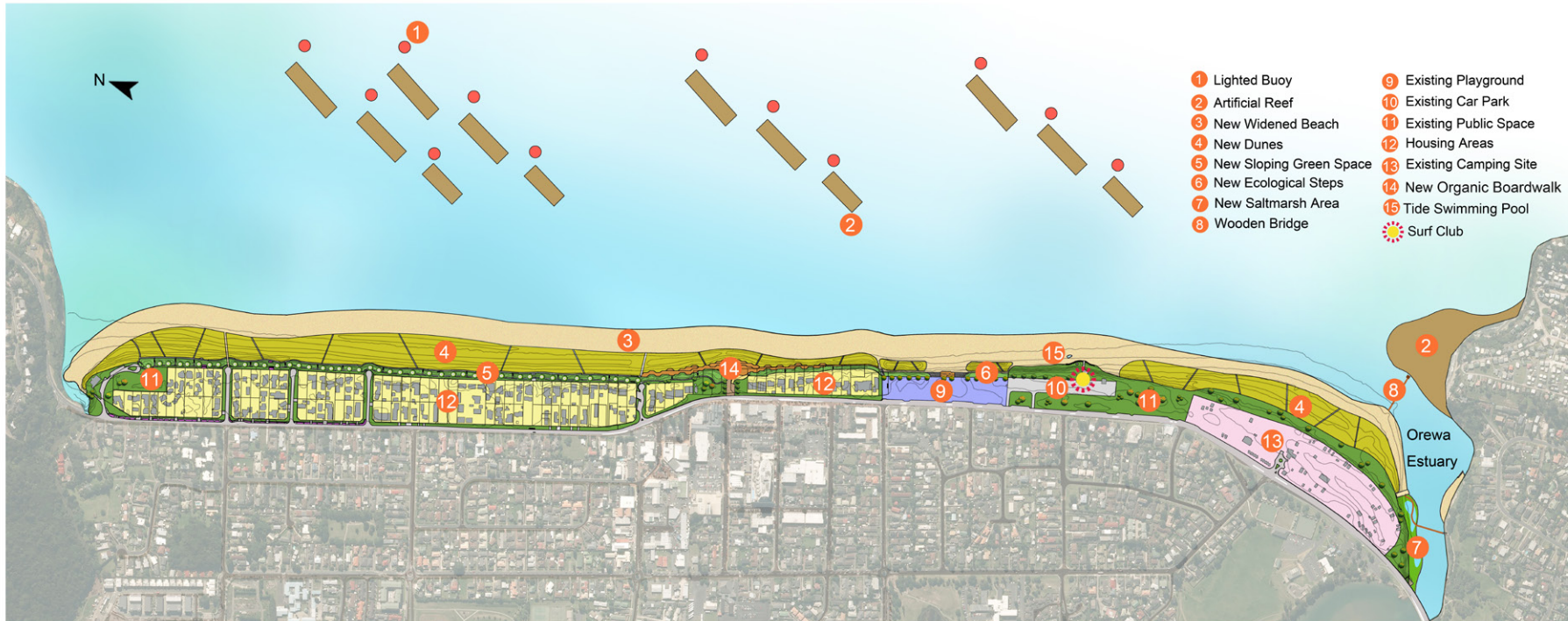


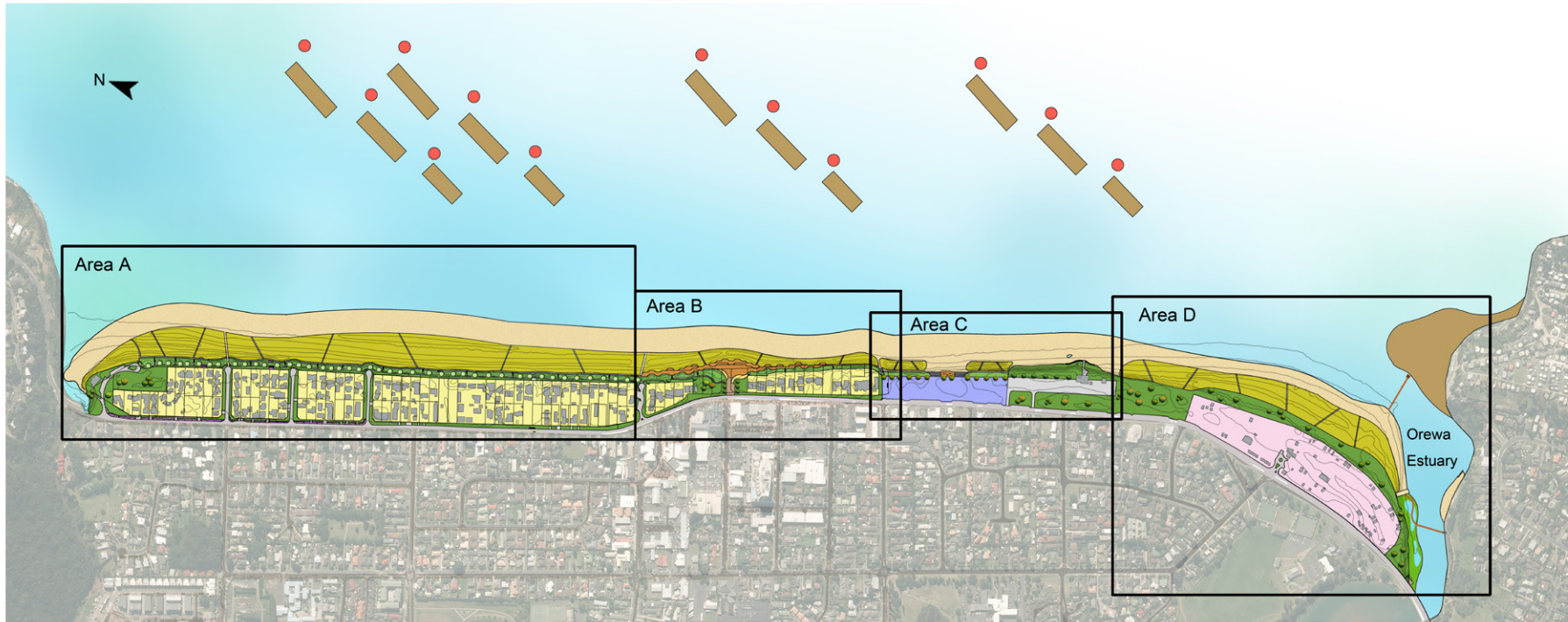
Figure 135. Phased Stages - Final Proposition

• **Final Proposition**

An organic boardwalk between the dunes and sloping green space is designed to provide an opportunity for the public to get close to nature. The design inspiration of boardwalk comes from the wooden fences that are used to structure dunes. The new design expands social interaction through the creation of seating, steps and intimate edges while providing a new shape to capture sand and form dunes over time, providing protection and habitat area for coastal wildlife, and creating a new beachfront landscape as well.

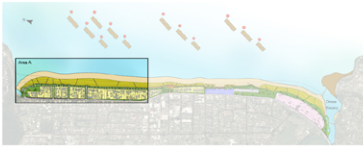
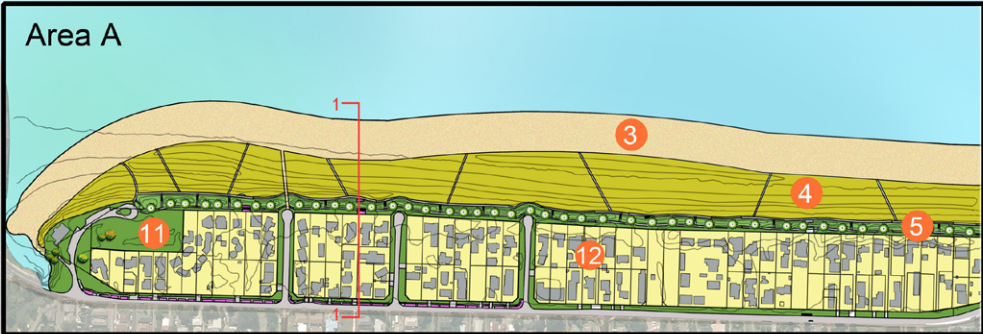


Master Plan - Final Proposition



Zones - Final Proposition

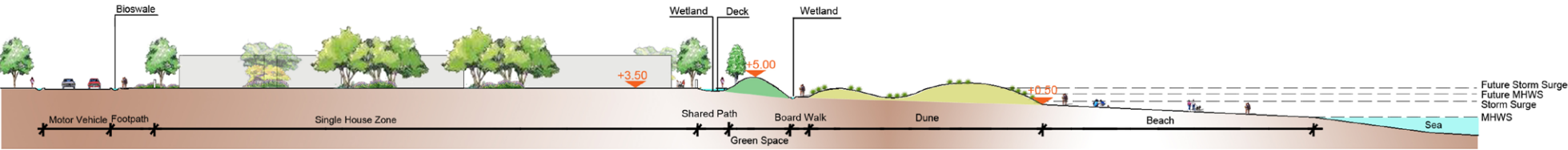
Sections – Area A (Final Propostion)



- 3 New Widened Beach
- 4 New Dunes
- 5 New Sloping Green Space
- 11 Existing Public Space
- 12 Housing Areas



Existing Conditions Section 1-1

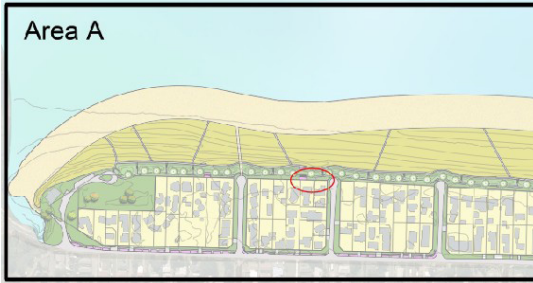


Proposed Conditions Section 1-1

Proposed stormwater wetland, boardwalk and sloping green space will create a beautiful environment for the community. Stormwater wetland can provide a storage capacity for runoff water, reducing the beach erosion caused by stormwater outlets. Proposed sloping green spaces are expected to resist future sea- level rise.



Existing

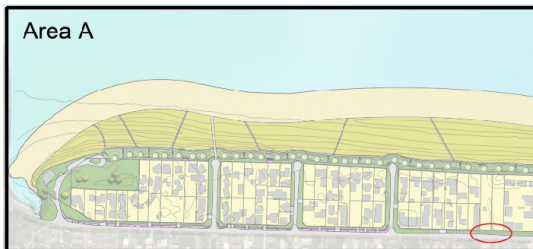


Proposed



Existing

Proposed bioswale can reduce the stormwater run-off, increasing public awareness about the coastal environment.



Proposed



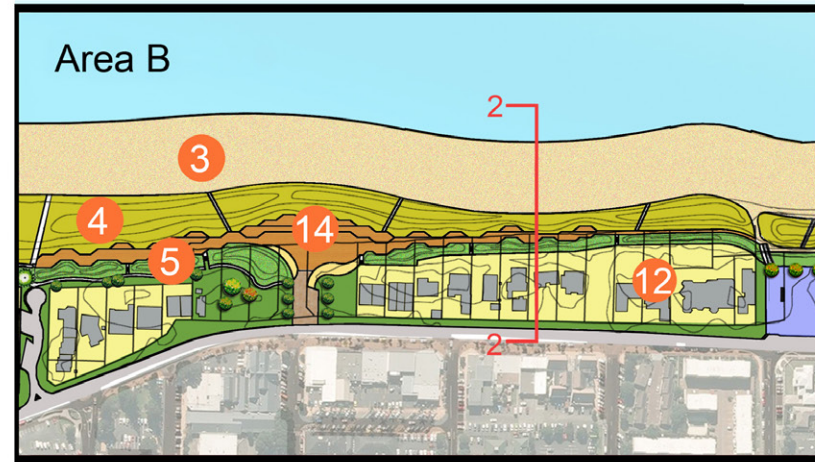
Existing

Proposed dunes and sloping green spaces can mitigate the storm surges and future sea-level rise. New boardwalk between those is designed to provide a healthy lifestyle for walking and cycling.

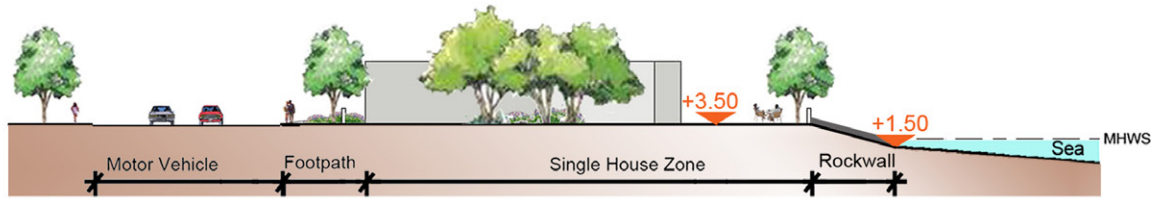


Proposed

Sections – Area B (Final Propostion)

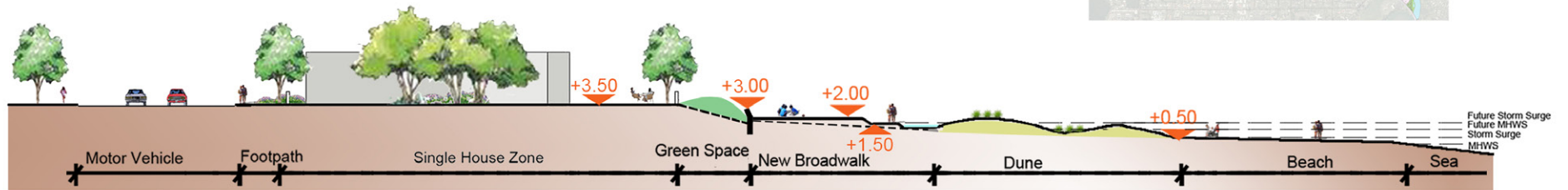
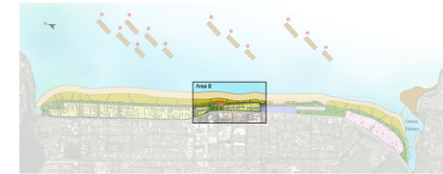


- 3 New Widened Beach
- 4 New Dunes
- 5 New Sloping Green Space
- 12 Housing Areas
- 14 New Organic Boardwalk



Existing Conditions

Section 2-2



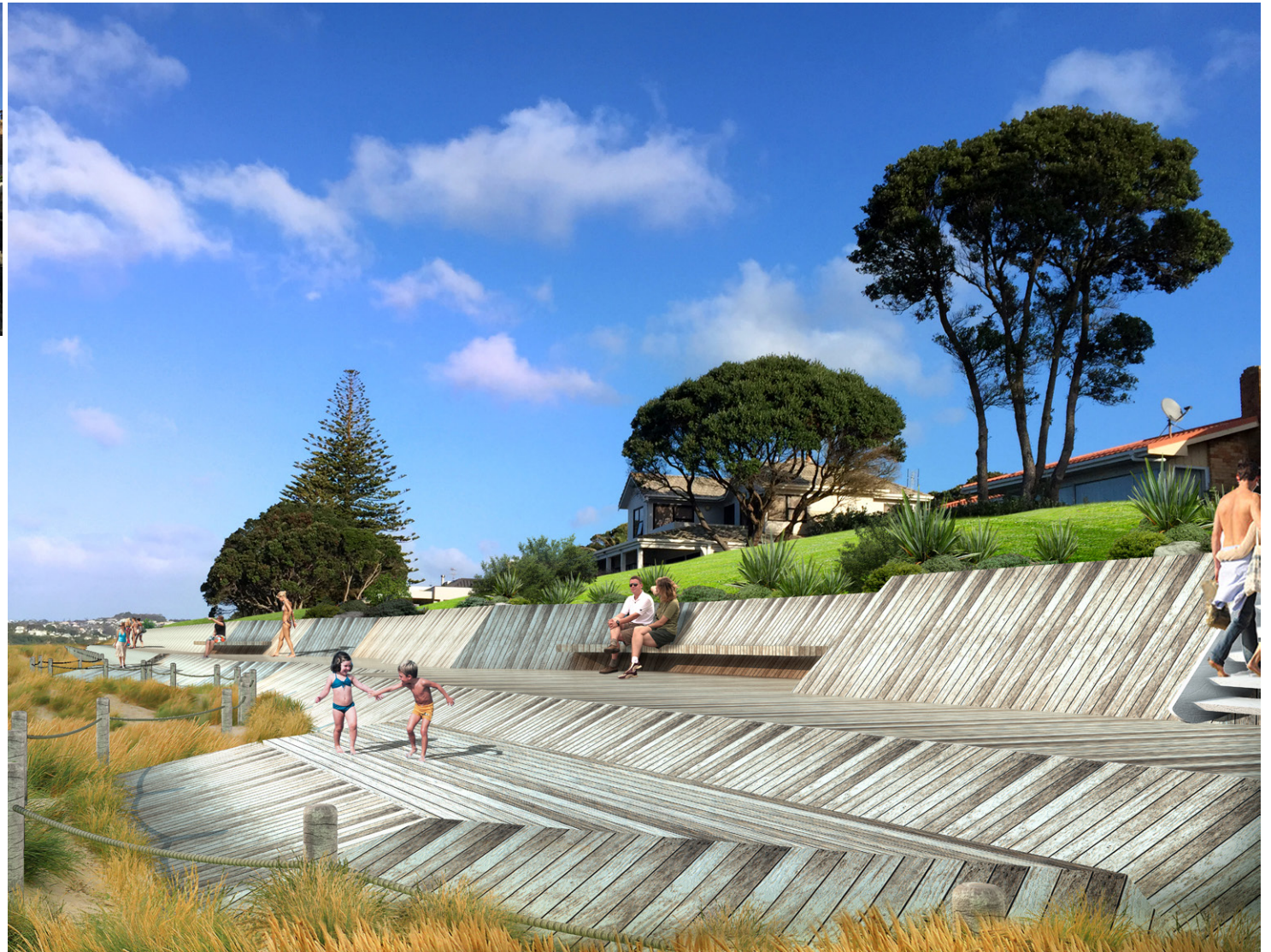
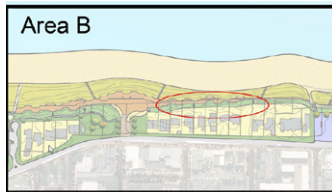
Proposed Conditions

Section 2-2



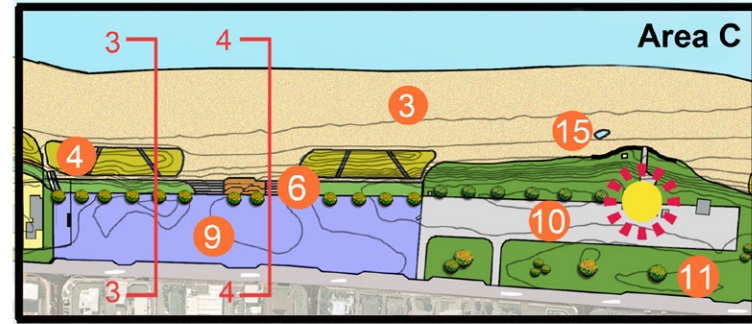
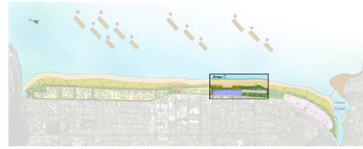
Existing

Proposed organic boardwalk can trap more sand for building dunes, creating a protection and habitat area. It expands social interaction through the creation of seats and steps.

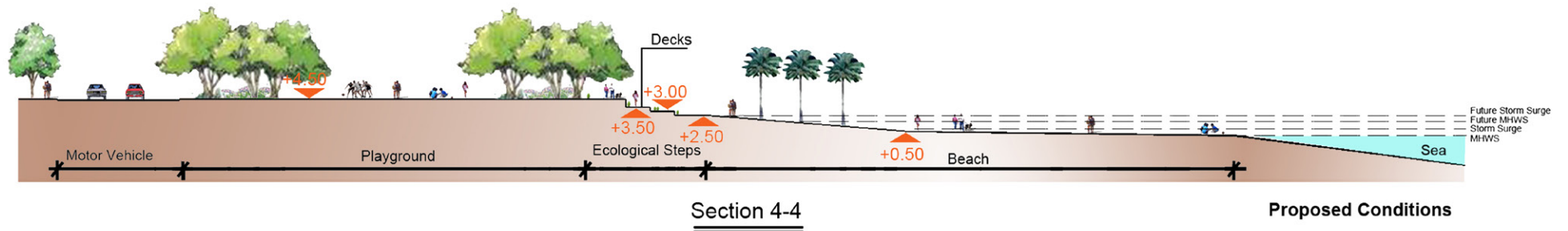
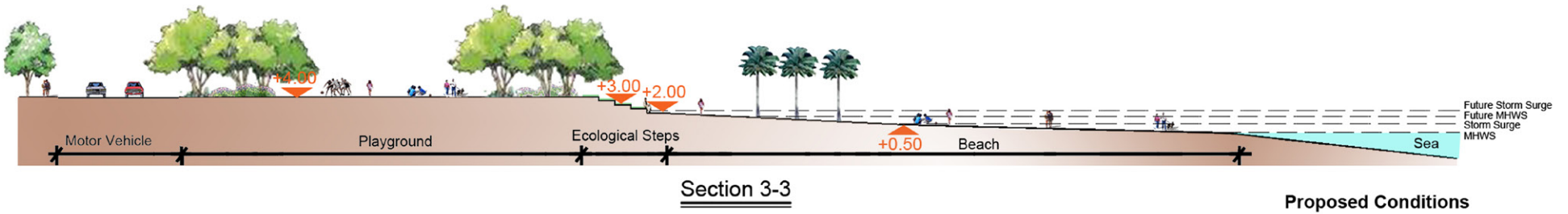
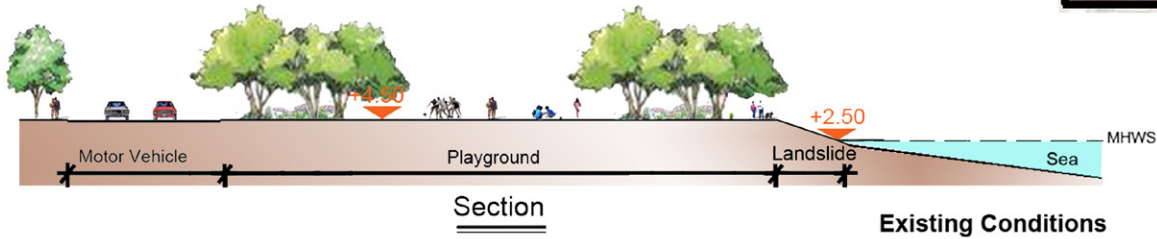


Proposed

Sections – Area C (Final Propostion)



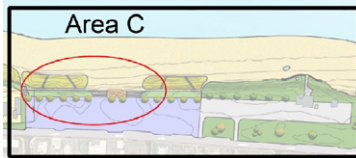
- 3 New Widened Beach
- 4 New Dunes
- 6 New Ecological Steps
- 9 Existing Playground
- 10 Existing Car Park
- 11 Existing Public Space
- 15 New Car Park
- 17 Tide Swimming Pool





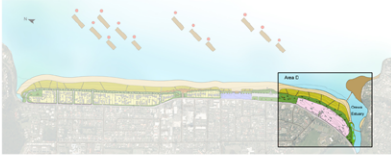
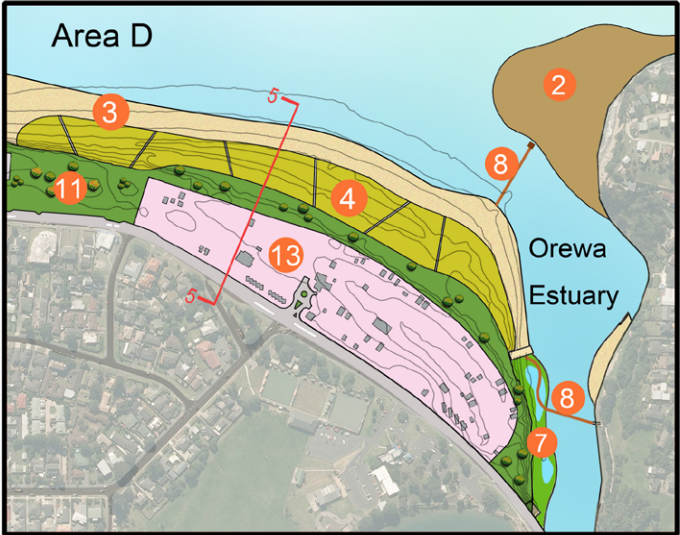
Existing

Proposed ecological steps and terraced wooden platform in front of the existing playground can reduce wave- induced erosion and provide a more flexible recreation area when sea level rises.

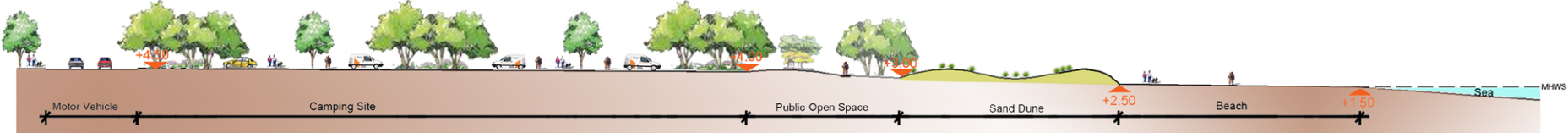


Proposed

Sections – Area D (Final Propostion)

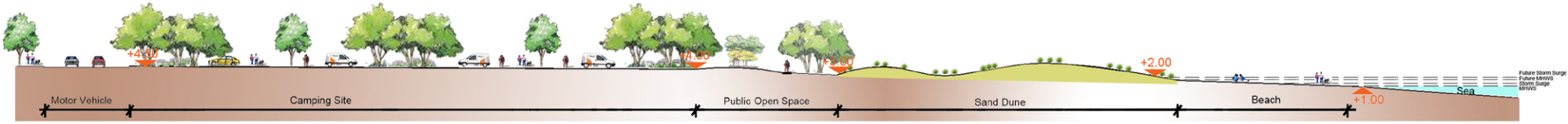


- 2 Artificial Reef
- 3 New Widened Beach
- 4 New Dunes
- 7 New Saltmarsh Area
- 8 Wooden Bridge
- 11 Existing Public Space
- 13 Existing Camping Site



Existing Conditions

Section 5-5



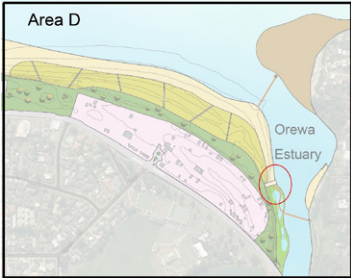
Proposed Conditions

Section 5-5

Proposed salt marsh can absorb rising sea level and trap sand for the shore. The wooden bridge is designed to strengthen the bonds between the adjacent community (Red Beach) to Orewa. Environmentally friendly concretes are designed on the intersecting edge between the proposed salt marsh and dunes. People can sit and play on them. Seaweed and algae will grow on their surface over time, creating a new ecology.



Existing



Proposed

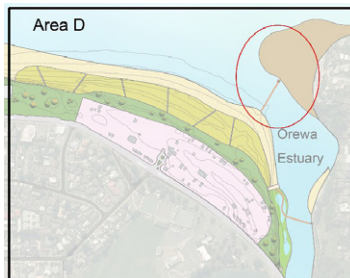
A wooden bridge with floating deck is proposed to provide an access for people to enjoy diving around the newly created Waitemata artificial reefs.



Existing



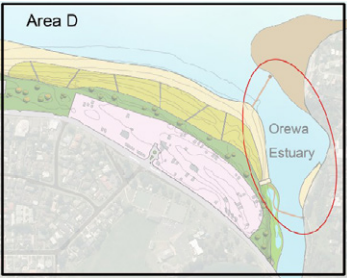
Proposed



The proposed salt marsh, dunes, wooden bridges and diving area will create a new coastal landscape for Orewa.



Existing



Proposed

6 Design Evaluation

6. Design Evaluation

In the research, ecological, economic, social criteria are used to test whether these design can achieve the proposed aim: “This research aims to explore resilient strategies and environmentally friendly interventions with an integrated vision to mitigate coastal erosion in Auckland”.

- Ecological Benefits

This proposition advocates a way of enhancing the resilient ability of coastal communities by emphasising the significant roles of natural functions to mitigate the effects caused by natural hazards. Artificial reefs, dunes and saltmarshes will help to deposit sand along the shore in Orewa, without causing negative effects to the coastal environment. The designed dune spaces, sloping green space and saltmarsh, are expected to resist storm surges and large waves. The proposed coastal edges will provide space for natural processes of the coast, creating new habitats and improving the resilience of the shoreline in Orewa.

- Economic Benefits

Abundant coastal activities (diving, surfing, swimming, walking) combined with the enhanced coastal environment will work together to improve tourism in Orewa, bringing a significant economic benefit.

- Social Benefits

In the design, public spaces (organic boardwalk, ecological steps, tidal swimming pool, etc.) provide more flexible social areas for the community when encountering extreme weather conditions. The designed wooden bridge in the saltmarsh area will strongly promote the connection between the adjacent community (Red Beach) to Orewa.

Consequently, the new proposition can improve the environmental, social and economic qualities for Orewa, and contribute to enhancing the resilience of the coastal community.

7 Reflection

Design Benefits

The proposed design can mitigate coastal erosion with no adverse effects to the coastal environment. In addition to environmental benefits, this design also provides social and economic benefits for the community, contributing building a resilient coastal community in Orewa.

The proposed design advocates a way of recovering the resilient ability of the coastline to mitigate the effects of natural hazards by emphasising the significant roles of natural functions. Differing from hard engineering methods, this proposed design will not cause negative effects to the coastal environment. Sand accumulation along Orewa Beach will be obtained by environmentally friendly techniques (artificial reefs, dunes, salt marsh). New green spaces, dune areas and salt marsh area, are expected to resist storm surges and extreme waves. These newly designed coastal edges will provide space for natural processes of the coast, improving the resilience of the shoreline in Orewa.

In addition to the environmental benefits, the proposed design can also improve the social and economic qualities that constitute the resiliency for a coastal community. In the design, public spaces (organic boardwalk, ecological steps, tidal swimming pool, etc.) will provide more flexible social areas for the community when encountering extreme conditions. The proposed wooden bridge in the salt marsh area will strongly promote the connection between the adjacent Red Beach and Orewa. In addition, abundant coastal activities (diving, surfing, swimming, walking on the beach) combined with the beautiful newly created coastal landscape will enhance tourism in Orewa, providing a significant economic benefit.

Design Limitations In the proposed design, the artificial reef system is a critical point for the next other stages. After the beach is widened, this will provide room for the construction of green space. However, the effectiveness of artificial reefs is subject to other factors, like weather conditions. Other factors will also affect the implementation of the design. Due to a lack of funds, the construction of submerged reefs, organic boardwalk, wooden bridge or other design elements may be delayed or cancelled.

Method Benefits After referring to relevant case studies, innovative theories and advanced techniques, this research method focused on the combination of adaptation approaches (protection, accommodation and managed retreat), compartmentalization concept and environmentally-friendly techniques. The adaptive approach is a holistic framework to deal with coastal hazards (such as coastal erosion and flooding); it provides an innovative method to consider all possibilities before making a final decision. The innovative concept of compartmentalization is a very important method that can contribute to decision-making for coastal communities. During this process, each compartment is analysed individually first, including ecological and socio-economic characteristics. And then, a corresponding approach (protection, accommodation or managed retreat) will be analysed and selectively applied to each compartment. Finally, an integrated method will be developed from the collection of different approaches. Specific technologies are developed, supporting each branch of different adaptation approaches. These works comprise my research method as a whole, contributing to achieving the final aim. This integrated research method can be used as an example in other sites and other similar research fields.

Method Limitations The research method in the project can be used as an example in other coastal settlements and similar research on coastal issues, but it has some limitations in other research contexts because of the different problems. For example, the adaptation approaches (protection, accommodation and managed retreat) can be widely applied to the coastal research context which normally has the similar issues such as coastal erosion, flooding and future sea- levels rise, but they may not suitable for other research fields. In addition, the key elements in a research context are very important and need to be considered when taking into account different research methods. Take coastal context for example, the general elements are topography, wind and wave patterns, but the general elements may be quite different in other research contexts.

8 Conclusion

Research Questions: This research set out to answer the following two questions: “How can adaptive landscape strategies be used to mitigate coastal erosion in sensitive areas?” and “How will these designs influence the resilience of a coastal community?”

Aims and Objectives: This research aims to explore some resilient strategies and environmentally-friendly interventions with an integrated vision to mitigate coastal erosion in Auckland. This purpose gives rise to three specific objectives:

- Understand the causes of coastal erosion.
- Refer to and analyse innovative theory, successful case studies and environmentally-friendly techniques that address coastal hazards problems (such as coastal erosion, rising sea levels) used worldwide. Advantages among them will be used reasonably in the research.
- Study and determine the typical characteristics of a resilient coast.

The Site: Orewa Beach, a popular holiday destination, has suffered from coastal erosion for a long time. Its approximately 3-km sandy beach is perceived as its most valued aspect. Extended periods of human activities along the shore combined with natural factors have resulted in severe erosion at Orewa. There is nearly no visible beach during high tide and the situation worsens during storm conditions.

Research: • **Theory**

This research is developed on the basis of ecological urbanism. From the theoretical study of adaptive design for ecological urbanism, I further understand that many issues we face today are within the context of living systems that are unpredictable and dynamic. This method builds ecological functions into a landscape so that it is more resilient to climate change and other environmental impacts. From this study, I learned about the concept of “safe-to-fail”, which allows changes to happen to some managed extent, helping to prevent a greater disaster. This innovative theory is very inspirational for me, and to some extent, it has changed my attitudes towards how to deal with the problems we face in cities today.

• **Techniques**

In order to achieve the goal of mitigating coastal erosion through the natural functions of coasts, three techniques (dunes, salt marshes, softened coastlines), which will not cause adverse effects to coastal ecosystems are referred to in the technical context. Dunes and salt marshes are natural elements in a resilient and healthy coast, working as the buffer zone between the land and sea and protecting the areas inland. Dunes can reduce high energy storms and wind forces, causing sand accumulated along the shoreline. Salt marshes trap the sand by plants and absorb rising sea levels. Softened coastline is an innovative concept to soften hard walls by building a wide base within the ocean and creating a soft coastline up to a height. By doing so, most of the wave energy during storm surges is absorbed by the newly created green spaces. Aside from the benefits of coastal protection in mitigating erosion, these three techniques can also contribute to biodiversity enhancement. From these studies, I further understand the significant roles of natural functions in protecting coasts.

- **Case Studies**

Relevant case studies including projects and proposals that address the coastal problems were reviewed. These design precedents revealed various ways to deal with erosion problems in different countries. Advantages were adopted from these studies to serve my research.

- **GIS Analysis, Fieldwork and Relevant Reports about Site**

GIS analysis, fieldwork and the study of relevant reports about Orewa Beach were important method used to comprehensively understand the site status and problems.

- **Design Results**

The site was split into four compartments according to their distinct land use. After the individual analysis of each compartment based on the innovative concept of compartmentalization, protection and accommodation were confirmed finally as adaptive strategies to be used. Five different techniques: artificial reefs, softened coastlines, an organic boardwalk, dune rehabilitation and construction of a salt marsh were utilised in the project. These proposed natural buffer zones along the coastal edge would effectively mitigate coastal erosion in Orewa. In addition, this proposed interface would be expected to create a resilient coastline to resist storm surges and one meter of sea level rise.

Answer Research Questions: Adaptive approaches (protection, accommodation and managed retreat) is a holistic framework to deal with coastal hazards, such as coastal erosion and flooding. The innovative concept of compartmentalization provides an important method and basis for decision making. Specific technologies are developed under branch of different adaptation approaches. These three parts constitute the adaptive landscape strategies in my research, contributing to achieving the final aim and answer the first research question: “How can adaptive strategies be used to mitigate coastal erosion in sensitive areas?”

Coastal resiliency depends on two key factors: the beach and sufficient space for coastal processes. These (beach and coastal green spaces) are the significant natural buffer areas between the land and sea, mitigating the risk of coastal hazards. In the proposed design, sand accumulation along the Orewa Beach is obtained by different techniques (artificial reefs, dunes, salt marshes). New green spaces (dune space, sloping green space, salt marsh area) are proposed on the coastal edge. For a coastal community, the social and economic benefits are two important parts to constitute resiliency. In the design, public spaces (organic boardwalk, ecological steps, tidal swimming pool, etc.) will provide more flexible social areas for the community when encountering extreme conditions. The proposed wooden bridge in the salt marsh area will strongly promote the connection between the adjacent Red Beach and Orewa. In addition, abundant coastal activities (diving, surfing, swimming, walking on the beach) combined with the beautiful newly-created coastal landscape will enhance tourism in Orewa, providing a significant economic benefit. Consequently, the design provides both social and economic benefits. Those designs can answer my second research question: “How will these designs influence the resilience of a coastal community?”

The Last Word: Overall, this research has demonstrated that adaptive landscape strategies can be used to mitigate coastal erosion in sensitive areas and enhance the resilience of a coastal community. The research method can be used in other coastal settlements and other similar research fields. However, it may be limited in other research fields.

Future work: There are totally four beach typologies in Auckland: barrier spits, harbour beaches, pocket beaches and open coast beaches. General features among these beach types are quite different from each other, such as sediment transport, wind, wave and sea currents. As a result, the design strategies in these settings would be dramatically different. In this thesis, the research focuses on a pocket beach in Auckland; other typologies are not included in the research extent. If I have the opportunity to proceed with the research work, I plan to examine more beach typologies in the research scope. This will contribute to forming a more comprehensive framework of coastal erosion research covering a diversity of beach typologies in the Auckland region.

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