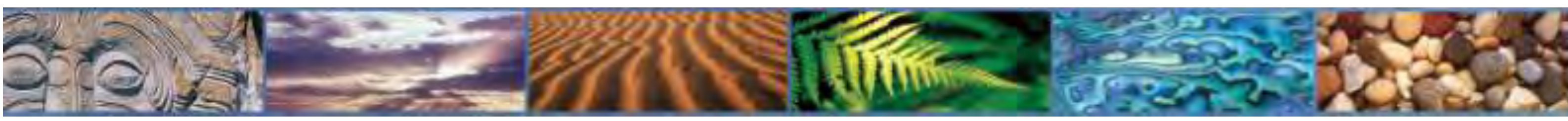
REPORT

Dunedin City Council

Ocean Beach Domain Reserve
Management Plan
Coastal issues and options

Tonkin & Taylor

ENVIRONMENTAL AND ENGINEERING CONSULTANTS



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Executive summary

As a result of significant shoreline erosion along Ocean Beach during 2007, Dunedin City Council (DCC) are seeking to develop a management plan for the Ocean Beach Domain that takes into account the existing and potential coastal processes operating within this area. This report summarises the existing and potential future coastal erosion situation, taking into account the effects of a range of possible sea level increases. The report also describes a range of potential generic actions to address the shoreline erosion and broadly identifies the general form, benefit and consequence of each option as well as indicative construction costs.

Ocean Beach is a high energy coast with a high sand transport potential. The eastern end of the beach has high wave energy, but typically with more shore normal wave action, whereas the central and western ends can be affected by longshore transport gradients, increasing erosion risk during southerly and south-easterly storms.

The current backshore dunes have been planted, stabilized and infilled to form land using a range of fill materials, including uncontrolled fill. The present shoreline is not representative of the natural system that existed prior to these human induced changes. The existing seawall at St Clair also encroaches into the natural beach system and is therefore affected by and influences local coastal processes at this location. The active management that has been carried out along the dune line has resulted in the land-sea interface being forced seaward and the dune over steepened.

The high tide lines in 1890 and 2007 are more or less in the same location indicating that the beach system has been relatively stable over the long term, but is affected by episodic storms that can cause significant fluctuations in shoreline position (drops in beach level in excess of 2 m by dune toe) and result in significant erosion of the over-steepened dunes (dune toe position fluctuations in the order of 15 m to 30 m). This erosion has resulted in exposure on the dunes of landfill material with localised deposits of industrial wastes. Sea level rise may increase shoreline erosion pressures and beach and dune erosion.

A risk assessment carried out as part of the overall investigations for the reserve has identified the central beach area is at the highest risk from erosion, due to the steep over-steepened dunes at this location and the presence of the landfill behind the dunes. Climate change and increased sea level rise will increase the current risks.

Thirteen actions were considered for managing the shoreline along Ocean Beach taking into account the existing processes and risks. These actions included the do nothing option, then progress to progressively more construction based solutions. For each action we provided a concept level estimate of construction cost, based on conceptual designs and basic unit rates, we also evaluate how well the proposed option provides erosion protection to the backshore in the short, medium and long term and what the risks are to the beach system. Finally we considered the likely consenting risk based on our previous knowledge of similar schemes. The results of this assessment are summarised in Table 9-2. All of the approaches involve some works removing material from the over-steepened dune in front of the historic landfill as protection of the dune toe would not prevent the risk of further erosion of the over-steepened dune.

Based on these actions a preferred set of options to manage erosion along the Ocean Beach foreshore is set out in Table 10-1 and Table 10-2 providing an adaptive management approach for the short (0 to 10 years), medium (10 to 50 years) and long term (50 to 100 years). The key area of focus is the area extending from the eastern end of the St Clair Seawall to the St Kilda Surf Club. The shoreline from St Kilda Surf Club to Lawyers Head does not need actions in the short to medium term.

The short term response for the central and western beach involves continuation of the current holding pattern that gained consent after 2007. This enables work to progress to a medium term solution that we have recommended to be either a buried backstop wall or managed retreat. Ongoing monitoring and evaluation is essential to provide a better understanding of the system and the timing requirements when these actions should be implemented as there is uncertainty on the actual rate of change associated with sea level rise and climate change effects.

We note there are potentially many other sub-options or alternatives, but these options provide the most feasible response. These options have an indicative cost range of between $4M and $8M over the next 10 years and from $8M to $19M in the medium term based on current costs, excluding consultancy and consenting costs. It is not considered appropriate to identify potential costs for longer term solutions.

1 Introduction

As a result of significant shoreline erosion along Ocean Beach during 2007, Dunedin City Council (DCC) are seeking to develop a management plan for the Ocean Beach Domain that takes into account the existing and potential coastal processes operating within this area. A series of studies have been commissioned to provide information on historic changes, coastal processes, values and attributes.

This report summarises the existing and potential future situation, including a range of possible sea level increases. It also describes a range of potential generic options to address the shoreline erosion and broadly identifies the general form, benefit and consequence of each option as well as indicative costs. The report was written by Richard Reinen-Hamill, with input from the DCC project team, including: Greg Sligo, Martin Thompson, David O'Malley, Mike Hilton, Peter McComb, Derek Todd and Martin Single.

2 Scope

Ocean Beach is situated on the south coast of the Otago Peninsula, a high energy coastline, exposed to winds from the north-east to south west, with strong winds originating from the south and southwest (Hilton, 2010). The Ocean Beach Domain extends a distance of about 4 kilometres from Lawyers Head to the headland at the St. Clair Salt Water Pools. The seaward boundary is the Mean Low Water Mark. The inland boundary adjoins the St. Clair Esplanade, Victoria Road and the boundaries of a variety of private and public properties along St. Clair and St. Kilda.

Situated within this area are the Kettle Park sports fields, situated over a historic landfill. The area under consideration is primarily the Council reserve and generally the coastal edge along Ocean Beach between Lawyers Head and the St. Clair Saltwater pools (refer Figure 2.1).

Figure 2-1 Location plan project extent (outer yellow box) and the location of Kettle Park sports fields (inner yellow box) (Source: Google)

In terms of coastal erosion, the likely range of dune line fluctuation has been taken from historic aerial photographs which are the only source of long term information on shoreline change (Todd 2010). Beach profile data is sporadic over the last 21 years (Todd, 2010), but provides an understanding of short term fluctuations in combination with the coastal process modelling (Met Ocean, 2010).

Future estimates of shoreline change has been undertaken using equilibrium beach theory, based on the assessment of sea level rise included in the report of Professor Blair Fitzharris (2010) that has extended on the previous assessments by the Intergovernmental Panel on Climate Change (IPCC). For the purposes of this study we have used 0.3 m, 0.6 m, 0.9 m and 1.5 m. These levels generally represent the range of possible sea level increases expected by 2100.

Option assessment has been based on previous experience of the author and Council's advisors. Costings for the various options have been derived based on the collective experience of the study team. Evaluation of the potential consequences of the various options is also based on experience and judgment.

3 Historic shoreline change

3.1 Large scale changes

The history of shoreline change has been evaluated by an examination of historic charts, maps, aerial photographs and oblique photographs (Single and Marshall, 2010 and Hilton, 2010). The earliest record is a map of the dune and high water line in 1890 through to the latest aerial photographs taken in 2009. Single and Marshall (2010) identified two key aspects of shoreline change:

- The destabilisation and subsequent reforming of the dunes and sand hills prior to 1914
- The development of the “straight-line’ contemporary shoreline.

The early cadastral survey plan, geo-referenced by Dr Hilton shows the high water line and dune system that paralleled Victoria Road. There was a lagoon and an overwash beach seaward of the dune line (refer Figure 3-1).

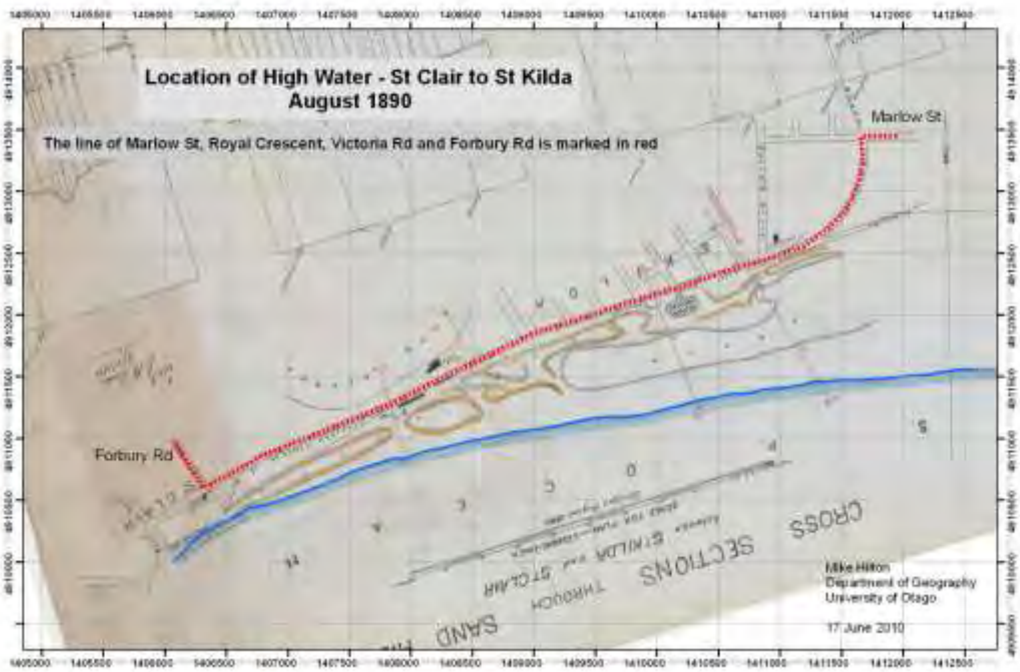

Figure 3-1 Location of high water, August 1890 (Source: Hilton, 2010)

This situation was modified due to significant dune planting of Marram in the early 1900’s to form a more parallel dune system with the present high water line. Based on aerial photograph information, the shoreline has remained in a reasonably similar state since 1952, possibly with a progradation (seaward movement) of the dunes from this time, although the high water line has remained reasonably constant (refer Figure 3-2).

Figure 3-2 Comparison of the 1890 and present high tide line inferred as the difference between the dry and wet beach

3.2 Short term changes

Short term changes in the beach and dune position have been assessed by an evaluation of beach profiles (Todd, 2010) as well as from information sourced from aerial photographs (Single, 2010). Beach change from beach profile data from 1997 to 2009 was assessed, although surveys were infrequent prior to the 2007 storms.

Beach profiles were set up at eight locations by Otago Regional Council, with irregular surveys carried out between March 1989 and June 2005. This information was augmented by topographic surveys in July 2004, September 2004 and February 2006. More detailed surveys were carried out since the 2007 storms using the original 8 survey locations from ORC and an additional 10 survey positions. Locations of the beach profiles are shown in Figure 3-3 to Figure 3-5.

3.2.1 Prior to 2007 storms

All dune sites at Ocean Beach experienced beach and dune-toe retreat in the period March 1989 to September 1992, with erosion distances and drop in dune toe elevation increasing in an eastward direction towards Lawyers Head. Maximum retreat of the dune toe at profile ORC17 (Lawyers Head) was 17.7 m associated with a 2 m drop in beach elevation across the beach profile.

All dune sites experienced seaward advance of the whole beach profile from September 1992 to March 1994. Advance of the Mean Sea Level (MSL) contour ranged from 14 m to 50 m at individual sites, while the dune toe advanced in the order of 14 m to 30 m. At the profiles in the central areas of the dunes (ORC 7, 11 & 12) this resulted in the dune toe being seaward of the 1989 position, and close to this position nearer to Lawyers Head (ORC 17).

Figure 3-3 Location of beach profiles at western end of Ocean Beach, showing the existing St Clair Seawall (Area 1) and the sand sausage wall to the east of the seawall to the Cultural Centre (Area 2) (Source: Todd, 2010)

Figure 3-4 Location of beach profiles at central area of Ocean Beach, from the cultural centre to the St. Kilda surf club including Kettle Park (Source: Todd, 2010)

Figure 3-5 Location of beach profiles at eastern area of Ocean Beach from St Kilda surf club to Laywers Head (Source: Todd, 2010)

All dune sites experienced retreat in the 10-year period between the surveys of March 1994 and July 2004. Retreat of the MSL contour was relatively constant at 35 m to 45 m, while the dune toe retreated 20 m to 35 m in the central portions of the beach, and 8 m at the eastern end (ORC17), closest to Lawyers Head. The trend of beach and dune retreat is constant with relatively high degree of storminess in 1997, 2002 and 2004. Drops in dune toe elevation approaching 2 m occurred at least twice in this period; firstly prior to the July 1996 survey (before storm records), and secondly prior to the June 2002 survey (after May 2002 storm).

Some recovery occurred over the summer of 2004-05, but not as far as the position in the initial 1989 survey; followed by further erosion by February 2006.

3.2.2 Effect of 2007 storms

The 2007 storms included the most potentially damaging single event on record since 1997, which occurred after a series of earlier storms over the preceding two months created the environment conducive to large rates of erosion.

The evaluation of the effect of the 2007 storms was complicated by the lack of pre-storm surveys, so a proxy position based on a laser survey in February 2006 was used as a base. However, the following observations were noted:

- All sand was stripped from the beach in front of the St. Clair seawall situated at the western end of Ocean Beach (refer Figure 3-3), but down cutting of the beach was limited to the depth of the rock platform.
- The geotextile sand sausages east of the seawall halted dune retreat at this location and beach down cutting was limited by the presence of the rock platform.
- The exposed sand sausages acted like a seawall during the last storm of the series producing “end effect erosion” along the next section of dune to the western end of Kettle

Park. Further "end effect erosion" in this section of dune is also likely to have resulted from the exposed rubble platform along the western end of Kettle Park. These effects combined with the possible presence of a nearshore rip channel in this area and lack of any form of dune protection or beach basement (e.g. rock platform), resulted in up to 2 m beach down cutting occurring and erosion of both the dune top and dune toe along this part of the coast.

- Along the west Kettle Park frontage in the centre of the beach (see Figure 3-4), the magnitude of beach down cutting was limited by the presence of the exposed rubble layer at the dune toe, which reduced dune toe erosion compared to the section of dune immediately to the west. This in turn reduced undercutting and avalanching on the over-steepened dune face, which reduced the magnitude of slumping of the clay cap on the top of the dunes. However, super-saturation of this unstable capping material in heavy rainfall in the weeks following the June storm resulted in some significant mass slumps of the capping material.
- At Moana Rua (see Figure 3-4), dune erosion was increased due to "end effects" from the exposed rubble, resulting in the construction of a rock filled wire mattress protection system. The presence of this structure resulted in further "end effects" erosion of the dune at the eastern unprotected end in the late July storm event.
- Within these localised variations there was a general trend of greatest storm effect on erosion and volume losses within the area bounded by the Marae to the central area of Kettle Park with diminished impacts, particularly on the dune top erosion, eastward towards St. Kilda (see Figure 3-4).

3.2.3 Post 2007 storms

An extensive survey campaign begun after the storms that has provided high quality information. In the first month after the storm up to 30% of the storm volume losses on the beach recovered. The beach accretion continued to around 50% after 2 months, with substantial sand returned in the central beach area. The recovery of sand was promoted by light to moderate wave conditions.

Significant beach volume fluctuation was noted, with up to 30 m^3/m change occurring within monthly periods in the area of the existing seawall. The slowest recovery occurred in the vicinity of Kettle Park. Beach volumes have generally continued to increase with beach volumes similar to those experienced prior to 2000. Dune volumes particularly in the central beach area have not yet recovered to the same degree.

4 Nearshore coastal processes

The existing coastal processes have been comprehensively investigated by MetOcean Solutions Ltd (Johnson, et. al, 2010). They identified the most significant wave energy originated from the southerly octant (around 72%) and around 8% occurred from the south-east. Modelling of wave, current and sediment transport was carried out for both southerly and south easterly storms. A tentative net longshore sediment transport capacity of around 200,000m^3/yr was estimated, moving towards the east.

For the more frequent southerly storms it was concluded that:

- The offshore bathymetry associated with White Island produces a gradient in wave height along the beach, with larger waves at the eastern end (see Figure 4-1).
- The longshore setup gradient drives a persistent westerly flow within the surf zone along the western third of the beach.
- In the central regions of Ocean Beach, there is bifurcation of the nearshore flows; with a broad westerly flow on one side and slight easterly flows on the other.
- At the eastern end of the beach flow is mainly eastward but also features recirculating regions associated with rip channels.
- Active erosion of the upper beach face and deposition of the sediments in the trough occurs primarily at the western end of the beach and this material is subsequently transported to the west. The model predicts shoreline erosion from just west of St Kilda Beach to the immediate east of St Clair Beach during storm events.
- Sediment transport vectors suggest net onshore transport through the central part of the beach, veering to the west in the nearshore regions.
- In the eastern third of the beach, the transport vectors are clearly directed to the east. Despite the higher wave energy and greater instantaneous sediment transport (with large re-circulating cells), the central and eastern parts of the beach do not exhibit erosion in the storms, and appear to be in dynamic equilibrium with the wave climate.

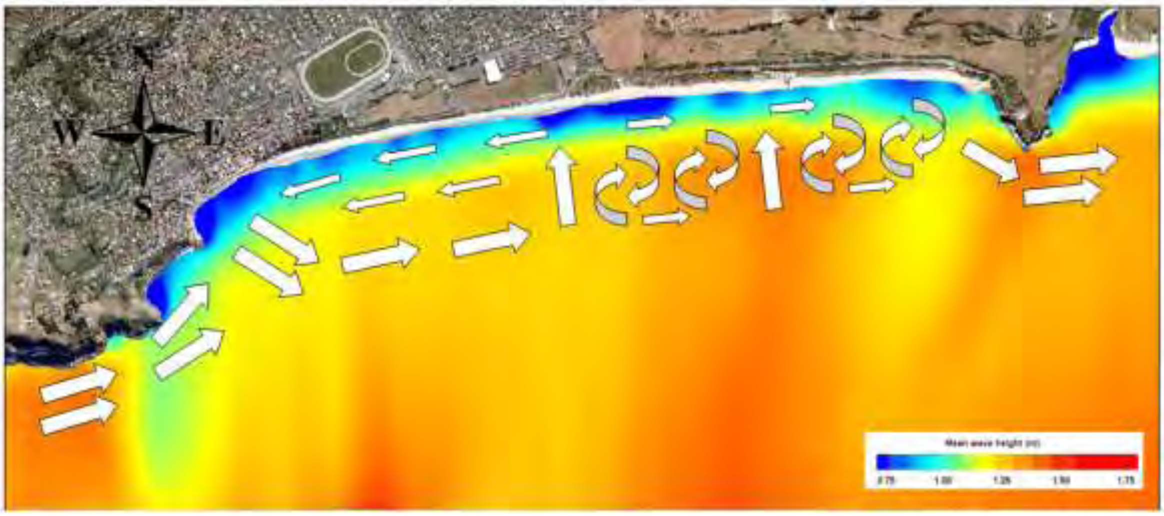

Figure 4-1 Conceptual diagram showing the mean sediment transport pathways during southerly storm conditions, along with the annual mean significant wave height (Source: Johnson, et. al., 2010)

The model outcomes for the south-easterly storm conditions are quite different. Here, the wave height gradient is reversed and there is more energy reaching the St Clair end of the beach. The current flows and sediment transport vectors are uniformly directed to the west, and there are no significant circulation cells (despite the same initial bathymetry); the along-shore flows are driven by the high angle of incidence between the waves and the shoreline, rather than by gradients in water level setup.

MetOcean (Johnson, et. al. 2010) also identified that regional currents are unlikely to significantly influence the nearshore and surf zone sediment dynamics, but would alter the net volumes of sediment moving into and out of the Ocean Beach coastal compartment.

5 Potential future situation

While the existing shoreline is dynamically stable there is a risk with future sea level rise that landward retreat of the beach face could occur. This would be as a result of higher water levels allowing greater wave energy to impact on the upper beach and dune system.

The potential shoreline change due to accelerated Sea Level Rise (SLR) is assessed using the modified Bruun Rule which assumes that the sediment supply and active beach width remains constant during a change in sea level (Bruun, 1988). The beach profile is likely to respond to these conditions with an upward and landward translation over time. The landward translation of the beach profile (**T**) can be defined as a function of SLR (**Δs**) and the active beach/intertidal slope (**tanα**) from MHWS to MLWS (Komar, 1991; Hennecke and Cowell, 2000). This relationship is given in Equation 1 and displayed in Figure 5-1.

The modified Bruun rule assumes only cross-shore transport of sediment along the beach profile and does not account for long-shore supply of sediment to the beach profile.

The modified Bruun rule also implies the cross shore beach profile is uniform in sediment type and slope. However, much of the shoreline is fronted by significant coastal features (channel and offshore shoal/spit). These features are likely to limit the cross-shore transport system that the Bruun Rule is based on. Therefore, the limit of cross-shore transport for shorelines areas landward of the parallel running channel is likely to be the channel. This potential effect is overcome by using the intertidal slope of the beach as input.

Although there are accepted unknowns due to climate change and limitations of the Bruun Rule, the methodology represents our best estimate with available/current information.

$$\Delta \boldsymbol{T} = \frac{\Delta s}{\tan \alpha} \qquad (1)$$

Where:

△T is the landward translation of the beach profile due to sea level rise (m)

Δs is the increase in sea level rise (m)

tanα Is the average slope of the embayment/intertidal flat (slope from MHWS to MLWS) taken at each beach profile location

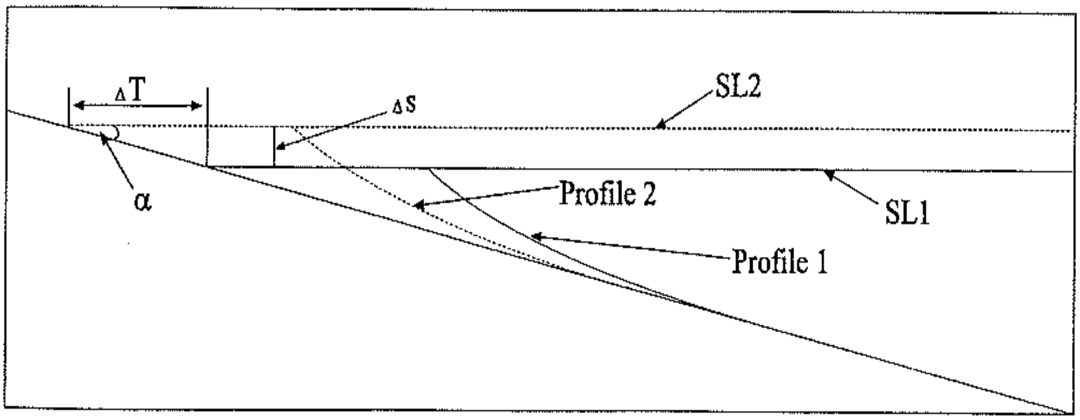

Figure 5-1 Horizontal translation distance of the beach profile under SLR (adopted from Hennecke and Cowell, 2000)

The following table sets out the potential dune-toe retreat for sea levels ranging from 0.3 m to 1.5 m. These levels generally represent the range of possible sea level increases expected by 2100.

Table 5-1 Projected shoreline retreat for a range of possible sea level increases

Sea level Increase (m)	Possible dune-toe retreat (m)
0.3	5
0.6	10
0.9	15
1.5	25

For planning purposes an allowance of future dune toe retreat of at least 15 m should be taken into account based on a sea level of 0.9 m. This level is slightly higher than the currently preferred sea level rise of 0.8 m by 2100 included in the MfE guidelines, but is consistent with their suggested increases to 2110. If this distance was added to the most landward location of the dune toe from historic observation, this is likely to provide a reasonably conservative assessment of the potential dune area at risk from coastal hazards over the next 100 years, excluding the effects of landslide and dune instability.

The effects of landslide and dune instability can be taken into account by applying a slope of some 32 degrees to the translated dune toe line. This is the currently observed slope based on Marram vegetation.

Therefore the final set back is a summation of the following:

Set back = most landward location of dune toe + storm effects + sea level rise effects + dune slope allowance

Sheets 1 to 3 in Appendix A show the resulting area susceptible to coastal erosion taking into account our knowledge of existing processes and our evaluation of potential climate change induced erosion hazard. We note that this does not include any safety or uncertainty factor, and an additional 20 m buffer could be considered prudent comprising an additional 10 m allowance for sea level rises difference between 0.9 m and 1.5 m and 10 m for extreme storm cut occurring when the dune and beach is already in an eroded condition or a flatter dune slope provision should other dune vegetation be used.

6 Summary of coastal issues

Ocean Beach is a high energy coast with a high sand transport potential. Prevailing winds are from the south-west, which transports sand landward.

The eastern end of the beach has high wave energy, but typically with more shore normal wave action, whereas the central and western ends can be affected by longshore transport gradients, increasing erosion risk during southerly and south-easterly storms.

The high tide lines in 1890 and 2007 are more or less in the same location indicating that the beach system is relatively stable, but affected by episodic storms. However, sea level rise may increase shoreline erosion pressures and beach and dune erosion.

The current backshore dunes have been planted, stabilized and infilled to form land. This has resulted in the land-sea interface being forced seaward and storm events can attack the over-steeped dune toe, causing significant erosion of the dune face. This factor affects mainly the central and western shorelines. Erosion pressures are likely to increase as a result of increased sea level rise.

The existing seawall at St Clair encroaches into the natural beach system and is therefore affected by and influences local coastal processes.

7 Landfill investigation

This section briefly summarises the outcomes of a ground contamination investigation carried out as part of the suite of investigations to support the development of the reserve management plan.

A ground contamination investigation of the coastal buffer zone has established that landfill occurs between Kettle Park Road and beyond Moana Rua Road covering a greater area than indicated by DCC records. The landfill materials extend to the coast and area exposed at several locations along the coastal dunes (T&T, 2011a). The investigation confirmed DCC records indicating industrial wastes were disposed within the landfill although the depth and variability of these materials have not been determined by this investigation. The investigation did confirm the presence of silt/sandy fill containing demolition materials and minor industrial wastes. It is this silt/sandy silt fill that is currently exposed in the Ocean Beach dunes. The silt/sandy silt fill is currently exposed on the coastal side of the Ocean Beach sand dunes, with exposures varying from the upper 2-3 metres of the dune to up to 6 m of fill.

Overall, the investigation results for the exposed fill on the coastal side of the sand dunes show that concentrations of most contaminants are lower than relevant criteria. However, four of the soil sample results from the dune face exceed the Site Specific Trigger Levels (SSTL) for benzo(a)pyrene (equivalent). Asbestos-containing materials are also present at several locations in the dune exposures. It is likely that the hotspots of benzo(a)pyrene and asbestos are related to the presence of minor industrial wastes. However, due to the general similarity of the fill material along the 750 m length of exposure in the dunes, localised deposits of industrial wastes may occur along the full length of the exposure. None of the nine samples collected from the beach itself exceed the relevant criteria.

This assessment indicates that, based on current guidance, long term exposure to these materials may present an unacceptable level of risk to users of the beach and dunes. This means that an adult or child coming into contact (eating, inhaling dust, touching) with the localised deposits of industrial waste situated within the steep dunes for a few hours each day over a long period of time (around 24 years for adults and 6 years for children) may be exposed to some health risk. However, it is possible that revised guidance in the near future may indicate that no such health risk exists should the trigger levels be raised. Any management decisions regarding these materials should consider this uncertainty and the conservative exposure duration assumptions used in calculating the SSTL.

This evaluation has not addressed the potential for ‘hotspots’ of heavier contamination to be exposed during dune erosion. Given the variable nature of deposited wastes, this potential must be considered to exist, and could give rise to higher contaminant levels and thus increase the risk to users of the dunes in the short or medium term. This potential should be considered in developing any management strategy for the dunes.

Overall we consider that, given the erosive environment at Ocean Beach, there is some potential for users of Ocean Beach to come into contact with Asbestos Containing Material (ACM) in the exposed dune face materials, but the likelihood of this is relatively low because of the small volume of ACM present.

None of the samples collected from the windblown sand exposed on the Kettle Park sports fields or surface soil collected across the playing fields and the recreational area west of Moana Rua Road exceed the relevant criteria. This means that, based on current guidance for parkland exposure, there is no short or long term risk to users of the playing fields or the recreational areas.

8 Risks

Risk assessment workshops have been carried out to identify the hazards, threats and opportunities associated with the coastal hazards, including the dune erosion, risk of breach, discharge of contaminants and flood risk.

The key risks associated with the existing seawall at the western end of the beach (Area 1 shown on Figure B1, Appendix B) are associated with wave overtopping via storm surge and tsunami. However, the risk of this occurring is tolerable, provided a management response is available to address the effects.

Along Area 2 from the end of the existing seawall to the Cultural Centre (refer Figure B1, Appendix B), the risk of erosion increases due to the unprotected dune and higher wave forces. However as development is reasonably landward of this area, the risks are also tolerable in this area but will become more significant as climate change effects increase the erosion and storm surge effects, requiring some action.

From the Cultural Centre to St. Kilda Surf Club (Area 3, Figure B1, Appendix B) the risk of erosion is high due to loss of actively used reserve land and the presence of the historic landfill and the risk of exposure and erosion of localised deposits of industrial waste. This risk could increase with increasing sea levels, requiring some response to manage these risks.

At the eastern end of the beach, from the surf club to Lawyers Head (Area 4, Figure B1, Appendix B) the risk of erosion is tolerable as there is a wider vegetated buffer between the beach and the road asset.

9 Possible actions

This section sets out considerations for managing the shoreline along Ocean Beach taking into account the existing processes and risks. We initially consider the effect of doing nothing, then progress to progressively more developed solutions. For each possible action we provide a concept level estimate of construction cost per linear metre of shoreline, based on conceptual designs and basic unit rates. This is to enable a comparison of the relative cost of each option. The combined costs of the preferred solutions are included in Section 10.

We also provide some assessment on the potential for ongoing repairs or remedial works that may occur, the potential effects on the existing beach system and the potential difficulties associated with gaining resource consents. We also provide a comment on the particular actions ability to provide backshore erosion management over the short (0 to 10 years), medium (10 to 50 years) and long (50 to 100 years) term.

We note that the linear metre construction costs estimates are based on simple concepts and generic rates and are only suitable to enable comparisons of various approaches. The costs are not sufficiently detailed for any more than preliminary budget indications at pre-feasibility level. Costs do not include fees or consent costs for the feasibility through to detailed design process.

Construction costs include a 15% allowance for Preliminary and General. This item includes for mobilisation, set-up and contractor management of the construction process. A lower and upper bound cost estimate has been developed including contingency rates of 20% and 100%. This spread of contingency costs is in recognition of the unknowns associated with the contaminated material within Kettle Park and uncertainty on the level of remediation treatment required. Costs will depend on the specific nature of the material to be removed and the quantity. We have applied a unit rate of $29/T from landfill material disposal that is around the same cost for the removal of contaminated sediments at the new rugby stadium. The contingency of 20% is then applied to these costs to provide a credible lower bound cost. The 100% value is based on a moderate rate of treatment of a proportion of the volume to be excavated (i.e. up to $58/T). We note that considerably higher costs may be incurred if greater degrees of treatment of the Kettle Park landfill are required (e.g. local area treatment costs have been as high as $310/T), but these tend to be isolated hot-spots and not readily applicable for a generic landfill volume. However, there is a risk, depending upon the material uncovered during the works, that larger volumes of contaminated material will require treatment so treatment costs may end up in excess of the value derived by the 100% contingency approach.

9.1 Do nothing

As discussed in Section 6 above and as shown in the plans in Appendix A, the do nothing scenario will result in episodic beach lowering and erosion of the backshore dunes. Should sea levels increase as predicted, there is also a potential risk of increased erosion and retreat of the dune face.

This is likely to have manageable effect at the eastern end of the beach from the surf club at St Kilda to Lawyers Head, as there is a reasonably healthy incipient foredune. However, it does have the potential to affect the more developed backshore from the St Kilda Surf Club to the start of the existing seawall along the St Clair’s Beach (i.e. Areas 2 and 3 as shown in Appendix B). This has the potential to expose the historic landfill situated under Kettle Park and also cause erosion close to, or extending into approximately a dozen properties along the western end of Victoria Road should the upper bound of climate change induced erosion occur. The eastern end of the St Clair seawall may also experience end effect erosion that could compromise the effectiveness of the wall at the eastern end.

While having no appreciable cost, the Do Nothing approach does not provide for the existing and future risks of shoreline erosion or manage the exposure risk of the historic landfill. However, it may be considered an appropriate short to mid-term approach for the eastern beach area, extending from the St Kilda Surf Club to Lawyers Head (Area 4, Appendix B).

9.2 Continuation of the existing holding pattern

The continuation of the holding pattern (effectively the status quo) is based on extending Council's current regime to manage beach erosion. These actions are in accordance with Resource Consent Nos: 2008.33, 2008.34, 2008.35, 2008.36, 2009.54, and 2009.55 that are due to expire on 20 August, 2014.

These approved works are part of the holding pattern that was put in place to protect the sand dunes following the emergency erosion control works undertaken in 2007. This holding pattern is proposed to remain in place while a long-term plan for Ocean Beach is developed. The consents also include retrospective consent for the emergency works (outlined below) that were undertaken in 2007.

The emergency works and holding pattern includes the following:

- The transportation of rocks and sand and stockpiling of sand at 2 locations adjacent to the beach
- Deposition and contouring of sand on the beaches
- The storage of machinery in the Kettle Park area
- The construction of a Reno Mattress to protect the existing sand sausages, and additional Reno Mattresses where necessary to protect vulnerable parts of the beach
- Removal of the clay capping and rubble for safety reasons
- Monitoring of the dune face and beach levels
- Dune management.

The holding plan extension approach focuses on reactive management responses to erosion that occurs at the western end of the beach from the end of the St Clair seawall to St Kilda Surf Club. The holding pattern approach has a current annual cost of around $300 per linear metre of shoreline per annum. If responses are required to manage periods of increased storminess, costs could increase to around $600 per linear metre per annum.

The holding pattern extension may be an appropriate short-term approach for providing backshore erosion management to the western end of the beach, but it does not fully provide for the existing issues and does not provide for the future risk of shoreline erosion. This approach will need to consider the potential for greater exposure of contaminated material on the dune face and develop appropriate risk management techniques to address this risk. An additional response plan would be required for managing areas of contamination within the landfill exposures. This could include extending fencing and/or signage as well as additional testing of exposed areas of landfill with appropriate responses developed depending upon the outcome of those tests.

The effect on the beach system and beach users is likely to be limited to periodic slumping of the dunes, including areas of landfill material and construction traffic required to carry out management works. The existing consents include the ability for the Council to carry out a number of approved works. Gaining consent for an extension of the existing consents to provide short term erosion management is expected to be reasonably straight-forward, provided a longer term vision and plan are considered. We note that application to extend the consent would need to be made at least 6 months prior to the current consents lapsing.

9.3 Dune re-shaping and vegetation

A significant factor influencing the perception of erosion of the beach is the over-steep dunes and the seaward encroachment of the dunes due to developments and infilling in the vicinity of Kettle Park. The over-steep dune slope erodes more readily when waves attack the base of the dune and increases the risk of exposure of the historic landfill material.

Part of this process was due to the introduction of Marram grass. This is an exotic sand-binding plant and dune builder, as was the dune plant of choice in New Zealand from 1900's to the 1970's. It tended to form taller steeper dunes and encourage seaward progression of the dune face due to the strong sand trapping properties.

Professor Hilton identified that a foredune developed in association with Pikao (Pingao) along the entire shoreline is unlikely to be readily established at Ocean Beach (Hilton, 2010). This is due to the extreme winds that can occur, particularly at the eastern end of the beach (refer Figure 9-1) that form transgressive dune systems. However, it may be possible to establish a Pikao dominant dune system along the western beach areas as these areas are more sheltered. However, to achieve this, it would be necessary to regrade the dunes to a significantly flatter slope and then plant the slopes, possibly with a mix of indigenous and exotic vegetation.

Typically dune slopes of around 32° (around 2(H):1(V)) is considered stable (this is the stable angle of repose of dry sand) and this slope is observed within the Marram vegetated foredunes at the eastern end of the beach. However, this slope is unlikely to be achieved unless Marram is used. Slopes of between 18° (3(H):1(V)) to 11° (5(H):1(V)) may be more appropriate for the less robust dune vegetation such as Pikao. Alternatively, it may be necessary to accept that a Marram planted dune system may now be the most appropriate edge protection due to its ability to thrive in the aggressive conditions at this location and to reduce the quantities and extent of excavation through the existing over-steepened dune face.

For the purposes of this assessment, we have assumed a dune reshaping using a 3(H):1(V) slope (refer Figure 9-2), but note that planting could be either native or Marram. This flatter dune slope will more readily adapt to erosion of the beach, without significant slumping and erosion of the dune face. For illustrative purposes, we have also identified the 2(H):1(V) slope that would be more indicative of a Marram vegetated dune system.

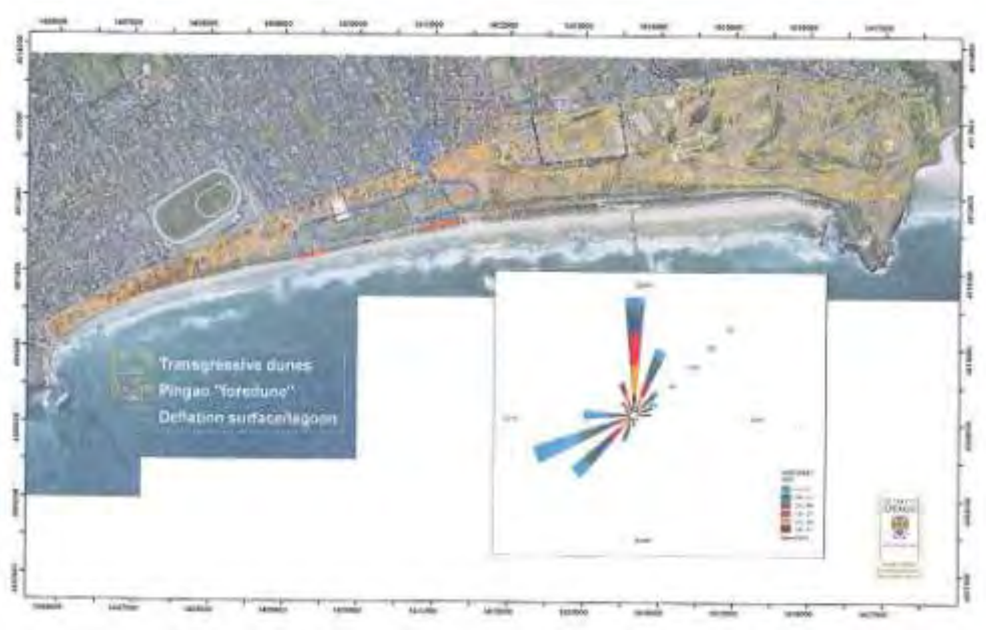

Figure 9-1 The major geomorphic elements of the pre-modified Ocean Beach dune system (Source: Hilton, 2010)

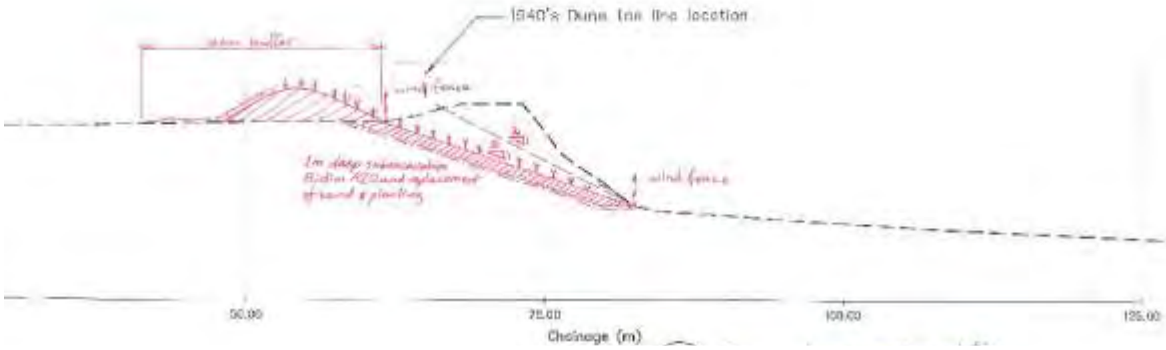

Figure 9-2 Dune reshaping and vegetation

A 3(H):1(V) grading back of the existing dunes and including a 20 m landward buffer from the newly formed crest is proposed to enable appropriate planting of the upper reserve area.

Based on preliminary data, it is likely that a proportion of the earthwork material would be contaminated to some degree with organics, debris and pockets of old landfill deposits. We have assumed 60% of the excavated volume would need to be disposed to an approved landfill, while the remaining 40% could be used as a cover to the cut surface, for beach nourishment or dune material.

Due to the presence of contaminated material, additional earthworks would be required to sub-excavate below the 3:1 formed surface and a barrier placed between the newly formed dune and the old landfill. We have assumed a 1 m deep excavation with geotextile fabric placed and excavated material replaced with clean sand and then planted.

The estimated construction cost of this solution ranges from around $4,000 to $7,000 per linear metre of shoreline protected. The majority of the costs are associated with the removal of unsuitable materials to landfill ($29/T) and the reshaping and reuse of clean sands as beach or dune nourishment ($8/T).

We note that the excavated dune material is likely to be finer than the beach sediments and therefore, more mobile. This implies it is likely to be removed from the beach system more rapidly than coarser sands and cannot be relied upon as effective beach nourishment.

This approach is likely to have a positive effect on the existing beach system, reducing the likelihood and frequency of dune erosion and restoring some degree of natural character. There is a reasonable likelihood that ongoing vegetation management and remedial works could be required to ensure a healthy dune system.

The proposed works are largely within Council's land and land based consents would be required. Some disturbance activity consents may be required from Otago Regional Council for construction works. Based on previous submissions received, this approach is likely to be supported by the wider community, although users of Kettle Park sports fields would be affected, with loss of playing areas, with some 10 m to 15 m encroachment on the fields, and some way of addressing this would be required. On balance, this approach is not expected to create significant challenges through the consent process.

Modest dune-reshaping and vegetation could provide a short term way of managing erosion effects in the central and western parts of Ocean Beach and providing some protection of the historic landfill. Depending upon the rate of future sea level rise and the effect on the coastal processes, this approach may also provide erosion management in the medium term (10 to 50 years). If Marram was used there would not be the need to modify the eastern end from St Kilda

Surf Club to Lawyers Head. If native vegetation was desired, the eastern end of the beach would require more significant modification to restore the shoreline to the transgressive dune field that once existing. However, this area is not a priority in terms of the risk assessment.

This approach is unlikely to provide backshore erosion management in the long term.

9.4 Managed retreat

'Managed retreat' is defined as any strategic decision to withdraw, or abandon private and public assets that are at risk of being impacted by coastal hazards (MfE, 2008). In this situation, the key assets at risk include the dune reserve and Kettle Park sports fields (overlying the historical landfill).

Allowing the shoreline to find a natural position and adjust to both the existing processes and the effects of climate change will almost certainly result in further erosion of historic landfill material, and possibly industrial wastes, to the dune face and upper beach area (T&T, 2011 a). Therefore, as shown in Figure 9.3, the managed retreat approach would require:

- Partial removal of the landfill to be back behind estimated shoreline movement over next 50 to 100 years (subject to required planning considerations). This would mean removing material so that the landfill was situated behind the landward extent of potential shoreline movement. We propose sloping back the dune crest 3(H):1(V) as described in Section 9.3 and planting in Marram or native vegetation.
- Removal of contaminated dune material seaward of the landfill to prevent this material from being discharged to the Coastal Marine Area (CMA) via the beach. It is proposed that this material will be disposed of to an approved landfill, clean sands would be retained for resurfacing the modified dune slope, similar to that described in Section 9.3. Landscaping and planting of the newly formed dunes.

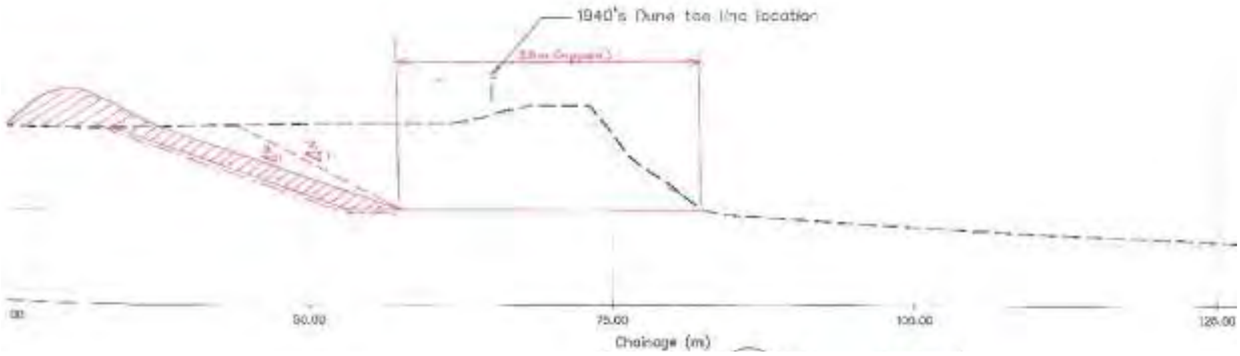

Figure 9-3 Managed retreat

There is flexibility in the both the quantum of set-back to be implemented and the timing to do so depending upon Council's consideration of risk. However, it is likely that some works will be required in the medium term as the current dune face is over-steepened and slumping periodically occurs. For the basis of this exercise we have assumed a full 25 m landward transfer of the dune toe. Progressive retreat would cost more over the period of works, due to the multiple mobilization and demobilization costs, but have a lower initial cost.

The estimated construction cost of this solution ranges from around $9,000 to $15,000 per linear metre of shoreline. The majority of the costs are associated with the removal of unsuitable material to landfill ($29/T), the reshaping and reuse of clean sands as beach or dune nourishment ($8/T).

Managed retreat would provide a long term approach to managing the coastal interface at Ocean Beach and maintaining a relatively natural coastal environment and would have a low risk of ongoing repairs or remedial work.

This proposal would have a significant effect on Kettle Park, effectively removing the ability to have sports fields at this location. There is also a greater risk of exposure to potential contaminants due to the greater volume of material to be removed. While the works provide a consistent approach to the New Zealand Coastal Policy Statement (NZCPS) and the desires presented in previous submissions for a restoration to a more natural situation, it is likely that submissions opposing the works may make the consent process more difficult that the dune re-shaping approach.

9.5 Sand transfer

The sand transfer would involve the excavation of sand from the eastern end of Ocean Beach and transferring the sand to the western end. To provide a sufficient buffer to moderate storm effects, it would be necessary to form a beach fronting the existing dunes of some 15 m to offset the typical storm fluctuations observed. To provide protection to the dune a similar dune reshaping and vegetation control would be required in addition, similar to that described in Section 9.3.

Sand transfer would require some 60 m^3 of sand to be placed per linear metre of beach along the western portions of the beach. Taking this volume of sand from the eastern beach area would reduce the beach width at the extraction area by around 15 m.

It is likely that the sand transfer process would be done by sand scraper picking up the sand and transferring and depositing the sand. This involves significant vehicle activity on the beach during the process, with traffic and pedestrian safety plans required and there would be associated works required including access ramps to the beach. Works would be constrained by the tide and there may be periods where sand is not available at the eastern end of the beach.

The total indicative cost for this approach, inclusive of the dune grading and vegetation ranges from $6,000 to $9,000 per linear metre of beach. Sand transfer would not necessarily provide effective relief to the over-steepened dune and a similar process to grade back and plant the dunes would be required as outlined in Section 9.3. An indicative sketch of a typical profile is shown in Figure 9.4.

Depending upon the incident wave conditions, this activity would need to be repeated as required. MetOcean estimated the theoretical transport capacity of longshore transport to be around 200,000 m^3/yr (McComb, 2010). This would suggest that this volume would need to be moved at least twice a year. However, the actual rates of longshore transport, particularly on the upper part of the beach are likely to be lower than the theoretical transport capacity. In addition, there are cross-shore processes and periods where natural processes return sand to the beach. We would envisage ongoing monitoring of the beach to be carried out and the activity enabled when the western beach was sufficiently low, provided there was sufficient sand at the eastern end. For budgeting purposes, we would imagine that the sand transfer activity would be required on around a 5 to 10 yearly basis, although this frequency could increase with ongoing sea level rise to be a more than annual event.

Subsequent sand transfers would cost around $1,000 per linear metre at current rates and this should initially be budgeted for every 7 years with an allowance of CPI. However, the transfer activity and frequency will be totally dependent on storm conditions and the state of the beach.

This proposal maintains the natural character of the environment as preferred by many of the previous submitters and is consistent with the NZCPS. However, it is considered that the consenting risk is moderate for this proposal. There will need to be consents sought from Otago Regional Council and there may be submitters who favour either less disturbance or more robust solutions.

Sand transfer could provide a short to medium term approach to managing the coastal interface at Ocean Beach and maintaining a relatively natural coastal environment. However, it could become a significant and regular disturbance activity and less effective should the predicted sea level rise effects occur.

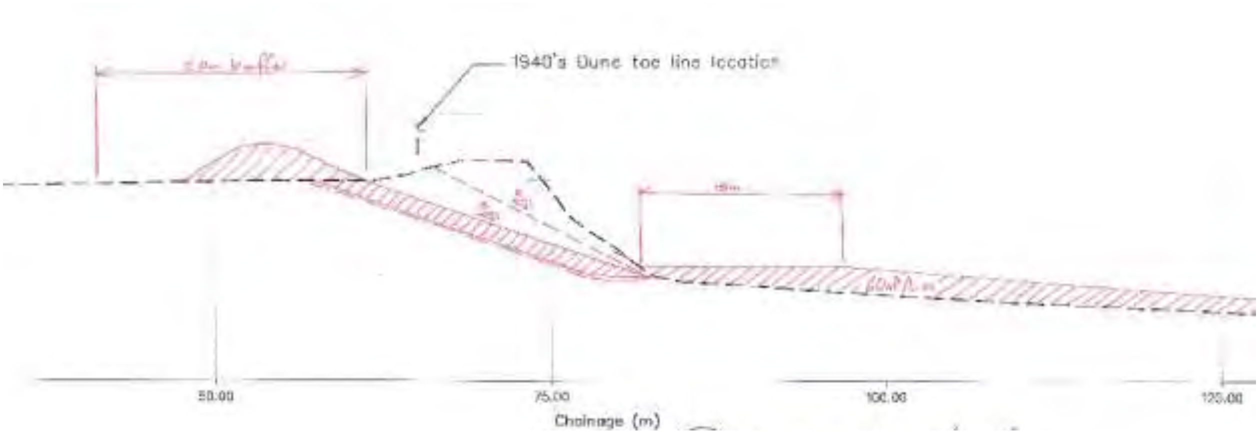

Figure 9-4 Sand nourishment/transfer

9.6 Sand nourishment

Sand nourishment would involve the importing of sand to Ocean Beach, rather than moving the existing sand resource from one end of the beach to the other as described in Section 9.5. The sediment report identified potential sources being dredging from Cross-channel and Taylor's Point in Otago Harbour or from either of the Blackhead quarries (Todd, 2009). It was identified that other sources could be used, but if sediments were finer, it was likely that more rapid losses would occur.

Sand placed along the western shoreline at a rate of around 60 m^3/m of shoreline forming a 15 m wide beach to buffer against storm attack.

Blackhead Quarries are some 10 km from the site and sand would be trucked to site and place on the beach by scrapers. This would require some 2,000 trips by 40m^3 truck carriers and a temporary haul road constructed down the edge of the dune to access the beach. We have allowed for a rate of $35/$m^3$ including placing and shaping.

Dredged sand from the Harbour would be likely to have a lower cost for the resource, but possibly higher processing costs, as size ranges may be more variable and transportation would require a barge, transfer from barge to truck, wharf charges and then haulage. Previous works suggest costs of up to $25/$m^3$ may be achievable. However, due to the uncertainties associated with grading size and volume, at this stage we have assumed the same unit rate for either source. Similar construction requirements and risks to the sand transfer alternative are likely for the sand nourishment approach.

Similarly for the sand transfer approach, we would envisage ongoing monitoring of the beach to be carried out and the activity enabled when the western beach was sufficiently low. For budgeting purposes, we would imagine that the sand nourishment would be required on around a 5 to 10 yearly basis, although this frequency could increase with ongoing sea level rise to be a more than annual event. We also note that there is a potential to import sand and then transfer it. This would reduce the risk of exposing the dune at the eastern end to increased wave action when sand was removed from this area.

In addition, the dune management as described in Section 9.3 would also be required to minimise the risk of landfill exposure.

The indicative construction cost for this approach ranges from $7,000 to $11,000 per linear metre of beach.

This cost should be included as a budget for repeat nourishments every 7 years. An alternative approach may be to import the initial volume then seek to transfer the sand on subsequent campaigns. This could reduce the ongoing costs to the sand transfer rate described in Section 9.5 above. Using the lower cost harbour sand could also reduce capital costs by around $1,000 per linear metre.

The consenting risk is identified as moderate. The approach is consistent with the NZCPS and reduces disturbance on the eastern beach area, but there may be issues raised regarding the transport of sand (noise/vibration) and the duration of works.

Sand nourishment would provide a short to medium term approach to managing the coastal interface at Ocean Beach and maintaining a relatively natural coastal environment. With the additional sand imported it is likely to be more effective than the sand transfer, so may provide a more effective longer term solution. However, it would become a significant and regular disturbance activity and less effective should the predicted sea level rise effects occur.

9.7 Buried backstop wall

A buried backstop wall would involve locating a wall along critical areas of Ocean Beach, but at a sufficiently landward location to be largely buried apart from during extreme storms and prolonged periods of beach lowering. This approach is currently favoured in many consent applications, over seawalls built along the present shoreline. However, depending upon the proposed location, the wall could become progressively exposed over time as a result of climate change with a net result of an exposed wall at some point in the future.

9.7.1 Seaward backstop wall

The most seaward location possible for the wall would be at the landward extent of the historic dune toe, based on the historic aerial photograph analysis. At this location the wall would need to be designed to provide some ability to withstand wave attack. Alternatively it could be located sufficiently landward to avoid the need to withstand coastal processes, and approaches such as a driven sheet pile wall could be considered to minimise disturbance effects.

The seaward back stop wall would be around 10 m landward of the existing dune toe (refer Figure 9-5). A rock revetment is the preferred approach for the buried backstop wall as it is more flexible and able to adjust to differing ground conditions. This would take the form of conventional rock armour layer with a slope of around 2(H):1 (V), overlying cushioning armour and a robust geotextile.

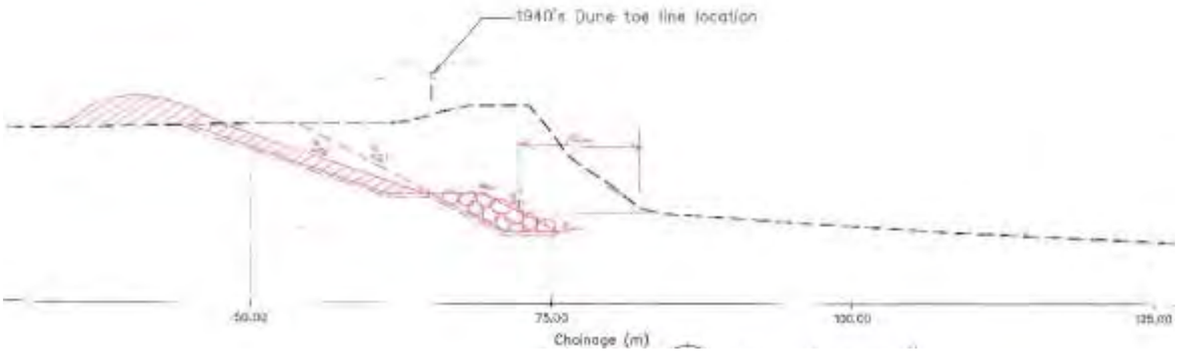

Figure 9-5 Buried backstop wall

The buried backstop wall approach is likely to require some removal of contaminated dune sediments and landfill debris and the upper slope would need to be graded back and covered with geotextile, similar to that described in the dune reshaping/managed retreat approaches.

There is a reasonable source of rock relatively close to the site and the supply and ex quarry rate is relatively low at $15/T. Haulage and placing increases the placed tonne rate to around $45/T. Overall the estimate construction cost for the seaward buried backstop wall and dune ranges from around $6,000 to $10,000 per linear metre of shoreline.

This approach provides for the maintenance of natural character, although disturbance during construction is high and there will be a period where re-establishment of the dune will be required. It is assumed that consenting risk could be moderate due to the increased disturbance and the presence of a wall.

The seaward buried backstop wall and dune management approach could provide a medium to long term approach to managing the coastal interface at Ocean Beach and maintaining a relatively natural coastal environment. However, the revetment is likely to become more exposed should the effects of sea level rise result in a landward migration of the dune toe and overtime could become permanently exposed.

9.7.2 Sheet pile backstop wall

The sheet pile backstop wall would be driven from the ground, with the crest situated around 1 m below existing ground levels. In this example we have proposed that the area seaward of the backstop wall would be allowed to change naturally over time that would result in periodic discharges of landfill material on the beach, dune slumping and low beach levels.

Overall the estimate construction cost for the sheet pile backstop wall ranges from around $4,000 to $17,000 per linear metre of shoreline, depending upon the level of tie-back required. The lower value is for an 11 m long driven sheet pile, while the larger value is for a 20 m long sheet pile with king piles at 1.8 m centres. We note that the tile back piles could be installed at a later date, which would create a lower initial cost for this option.

This approach effectively creates a do nothing approach to the management of the coast but provides certainty on the land area that is required to be protected. As the wall becomes progressively exposed there is likely to be significant visual impact.

Due to the ongoing erosion and slumping of the dunes and the progressive discharge of landfill material into the CMA, it is considered to have a negative effect on the existing beach system.

It is assumed that consenting risk could be moderate due to the increased disturbance and the presence of a wall. There may also be complexities required to be addressed regarding changes to groundwater conditions and effects of the wall on the ground water.

The sheet pile backstop wall approach could provide a medium to long term approach to managing the coastal interface at Ocean Beach.

9.8 Seawalls or revetments

A seawall or revetment is a traditional solution to managing shoreline erosion. A seawall is typically a fabricated structure, such as the existing concrete panel wall system present at the western end of the beach. These can be relatively steep (or vertical) and are largely impermeable. Examples of seawall configurations are shown in Figure 9-6. A revetment is formed from rock armour. These structures are permeable and sloping, therefore can tend to occupy more space than a seawall. An example of a rock revetment at Oamaru is shown in Figure 9-7.

The crest of the wall would need to be located slightly seaward of the dune toe to enable access along the crest and to avoid significant disturbance to the existing over-steepend dunes.

For a rock revetment, the structure would extend some 22 m seaward of the edge of the footpath, occupying existing dry beach. Based on preliminary sizing, a rock revetment would need to be formed from 1T to 3T rock boulders overlying a layer of cushioning rock and geotextile placed on a formed sand sub-grade. A crest elevation of around 5 m RL would be formed and the base of the wall situated at 0 m RL, with a dutch-toe extending out from the base to take into account potential scour effects and localised lowering of the beach. A typical section is shown in Figure 9-8.

To provide access along the crest of the revetment a concrete path or similar could be provided for, with a minimum width of around 3 m. Stair access to the beach could also be provided at discrete locations. This would also be done using marine grade concrete. We have assumed two access points along the seawall. Landward of the path the dunes would be graded back and planted, similar to that described in Section 7.3, but the volume of material required to be disposed of is less.

Indicative costs for the rock revetment range between $7,000 to $11,000 per linear metre.

For a (near) vertical wall we would anticipate a slightly higher structure than for the rock revetment as there is less energy absorption and dissipation for an impermeable structure. We have arbitrarily selected a crest elevation of around 6 m and the crest of the up-stand wall of around 7.2 m. This is also higher than the existing wall at St Clair's, which is also appropriate as there is greater wave energy at this location (MetOcean, 2010).

We would anticipate ground conditions to be less favourable for foundations than at the western end of the beach, so it is likely that some foundation improvement would be required. We have allowed for 5 No. 8 m long timber piles to be driven per m along the base of the wall to provide support to the superstructure. The wall itself would extend from -1.0 m RL to 7.2 m and be constructed either from cast in-situ marine grade concrete or from a combination of formed and pre-fabricated panels. The backshore area would be 5 m wide, providing a similar dimensioned promenade as exists at the western end of the beach and the dune slope above RL 6 m would be graded back and planted.

Indicative costs for this approach are in the order of $25,000 to $39,000 per linear metre rate.

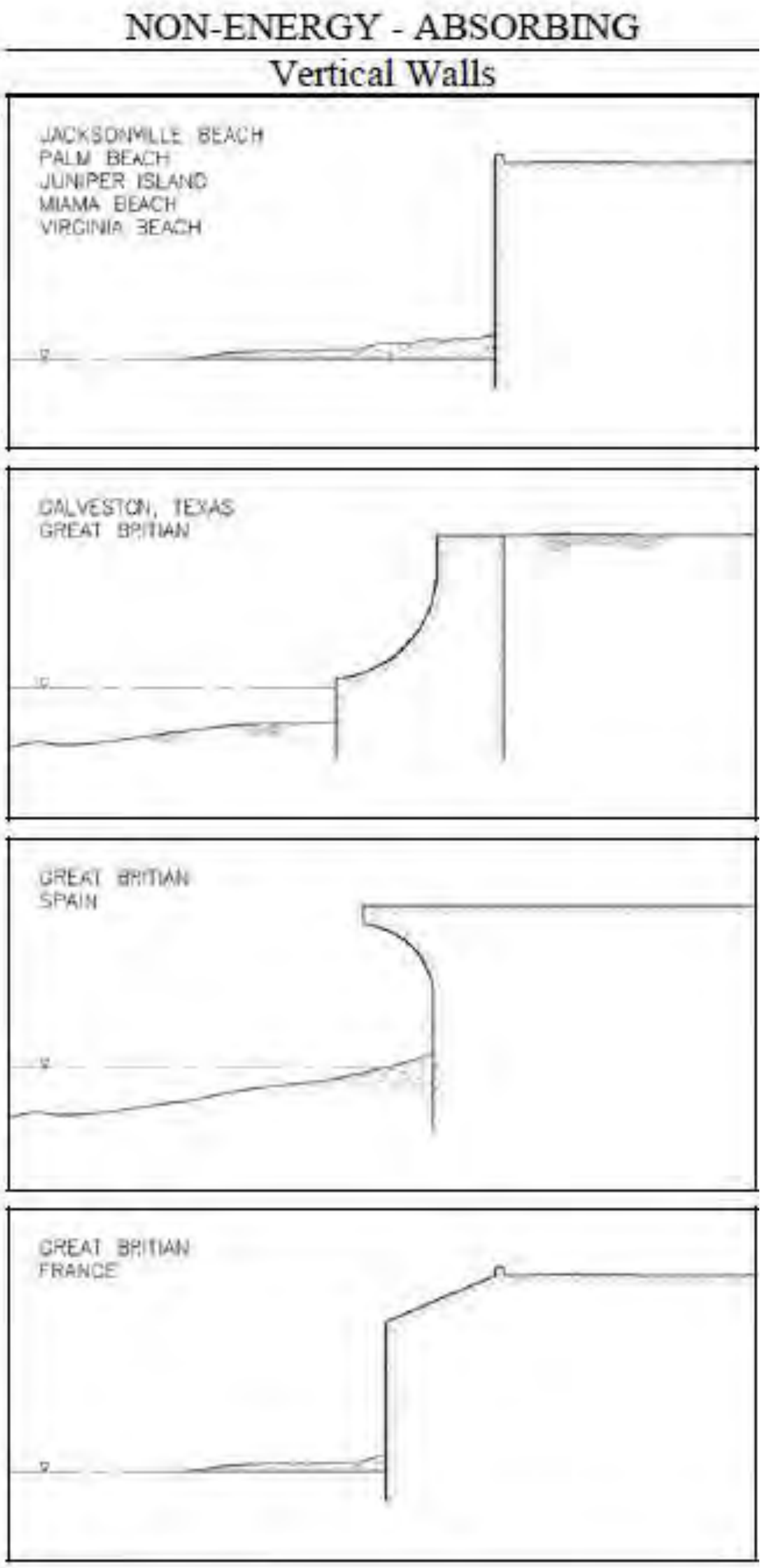

Figure 9-6 Examples of typical seawall configurations (Source: CEM, 2006)

Figure 9-7 Rock revetment at Oamaru

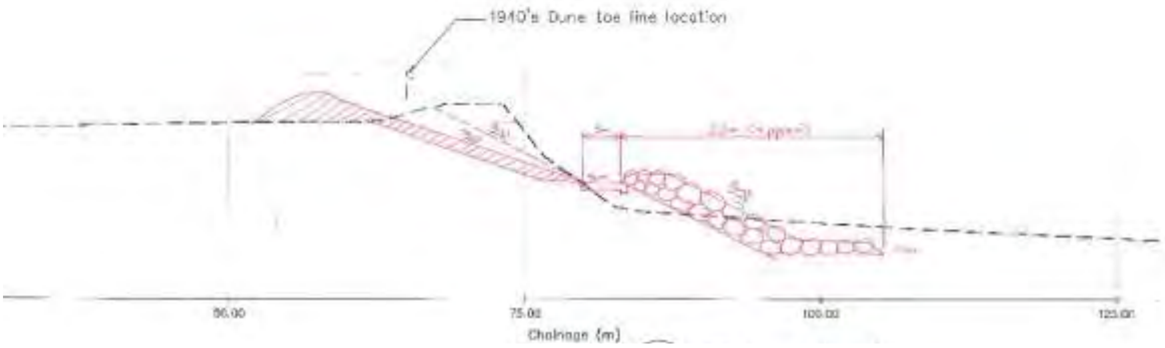

Figure 9-8 Rock revetment

These approaches should require relatively low ongoing costs for repairs or remedial works, although the risk of damage is likely to increase over time. From experience, remedial works are typically focussed on access ways and appurtenant structures associated with the revetment or seawall.

Both structures are likely to receive significant opposition due to the impact they will have on amenity, natural character and visual impact for the beach users. Therefore the consenting risk for these structures is high.

Both the seawall and revetment approach could provide a long term solution to managing shoreline erosion and protecting the existing landfill. However, they do not enhance the beach amenity. A seawall or revetment would create a significant barrier separating the beach from the backshore dune and could also result in a flatter beach seaward of the wall due to wave reflection off the structure. The vertical wall occupies less space and therefore theoretically enables a greater use of the beach. However, the impermeable nature of the wall leads potentially to greater effects on coastal processes and a higher structure to maintain overtopping rates to allowable levels.

9.9 Groynes

Groynes are protection structures which are used to control the natural movement of beach material (Fleming, 1990). Groynes are typically constructed from stone, concrete or timber that extends perpendicularly from the shore. The purpose of the groyne is to retain sand and reduce the effect of longshore drift. Figure 9-9 and Figure 9-10 show a typical conventional groyne field and detail of an individual groyne.

Westhampton Beach, Long Island, New York, 18 Jan 1980 (courtesy USAED, New York)

Figure 9-9 Example of a groyne field along a high energy coast (Source: CEM, 2006)

The Met Ocean report (2010) identified the presence of an offshore trough that carried circulation flow from the centre of the beach to the east. This trough can exacerbate shoreline erosion, particularly during strong wave conditions, as the increased flow would tend to erode sand from the adjacent shoreline. At the eastern end of the beach there was no significant longshore transport trend, suggesting cross-shore, rather than longshore transport dominated, as groynes would be less effective.

Therefore, the purpose of the groyne in this instance would be to maintain the position of the nearshore trough along the central and western areas (i.e. Area 1 to 3). Based on the bathymetric information contained within the MetOcean report, the groyne length would need to be around 100 m long. Fleming (1990) suggests a typical groyne spacing of between 0.8 to 2.7 m, or between 80 m and 270 m in this instance. For the purpose of this study, we assume a spacing of around 175 m, averaging between the two ranges. However, we note that a model study would be required to confirm actual configurations and also the potential effects of the groynes on the wider beach system, particularly if the groynes would result in changes to longshore drift patterns and potential adverse effects elsewhere.

The shoreline required to be protected extends from the St Clair Saltwater pools to the St Kilda surf club, a distance of around 1.8 km. This means around 10 groynes would be required. At this stage, we have assumed that the groynes would be constructed from quarried rock some 2 m high, with a sloping profile extending to just above MLW at the toe of the groyne.

It is likely that beach nourishment would be required as well to fill in the groynes as a way of minimising potential adverse effects. It is assumed that 80,000 m^3 (some 44 m^3/m) would be sufficient to maintain a reasonable beach width. In addition, a dune management approach, based on the method set out in Section 9.3 would be required to manage the dune stability and risks associated with the historic landfill.

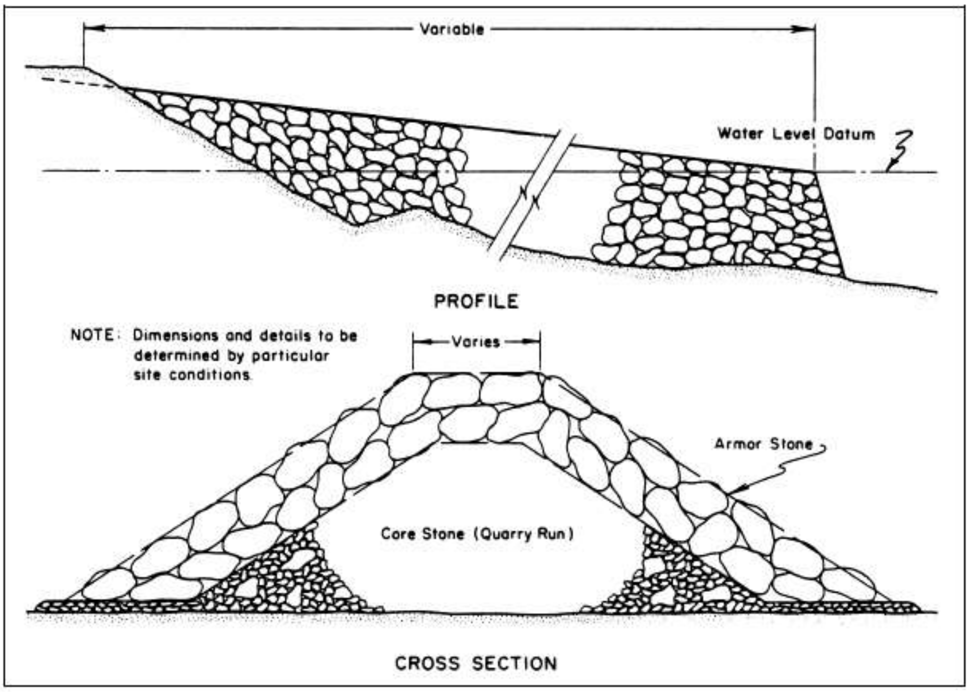

Figure 9-10 Typical cross-section of a conventional rock groyne (Source: CEM, 2006)

The cost for constructing the groynes has been based on twice the handling cost of the land based rock due to the requirement of working within the surf zone. The indicative construction cost for a groyne field, nourishment and dune works ranges between $6,000 and $10,000 per linear metre.

With works situated in the surf zone, the risk and cost of any remedial works or repair is significant, therefore there is a high risk associated with ongoing repairs or remedial works. It is also possible that the groyne field may have adverse consequences to the wider system as well as creating a significant change in natural character on the beach itself.

It is anticipated that these structures could have a significant consenting risk with objections likely from beach users, surfers and those wishing to retain a natural environment.

The groyne approach may have the potential to provide a medium to long term solution to managing beach and dune erosion. However, the risks of potential adverse effects as well as its effectiveness would need additional investigation. A detailed feasibility assessment would be required to confirm these effects prior to progressing with this approach, particularly with regard to the possible changes and effects on the nearshore trough system and both the net and gross longshore transport rates.

9.10 Offshore breakwaters

Conventional offshore breakwaters provide wave sheltering, reducing wave energy behind the structure and modifying the incident wave direction by a combination of diffraction and refraction. These structures can be emerged or predominantly submerged. The schematic in Figure 9-11 shows the typical function and expected shoreline response in the lee of an offshore breakwater and Figure 9-12 shows a photograph of a field installation in the USA.

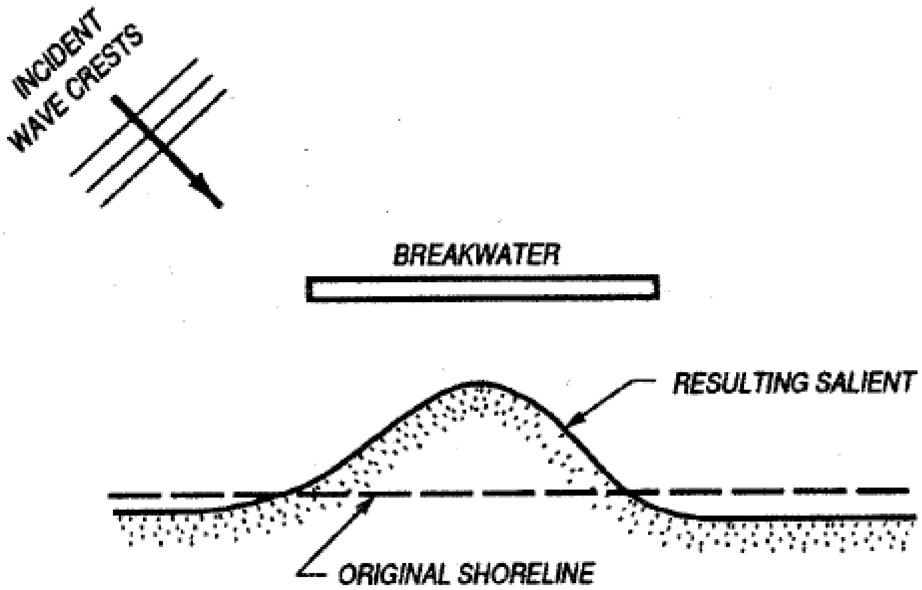

Figure 9-11 Typical function of an offshore breakwater (Source: CEM, 2006)

Figure 9-12 Example of an offshore emerged breakwater off the USA coastline (Source: CEM, 2006)

We note that the offshore structure encourages sediment build up, but typically with sand moved from the adjacent shore. Therefore, in order to maintain a beach buffer, nourishment is also required. This could be by sand transfer (as in Section 9.5) or beach nourishment (refer Section 9.6). Similarly a dune management approach as set out in Section 9.3 would also be likely.

The key variables required to be considered are set out in Figure 9-13. While there is significant uncertainty in the science to design the planform of these structures, the typical rule of thumb for developing a moderate bulge in the shoreline in the lee of the offshore breakwater (called a salient), is that the breakwater should be situated around twice its length offshore and the gap ration to reduce erosion effects is around 0.8 times the length of the breakwater (CEM, 2006).

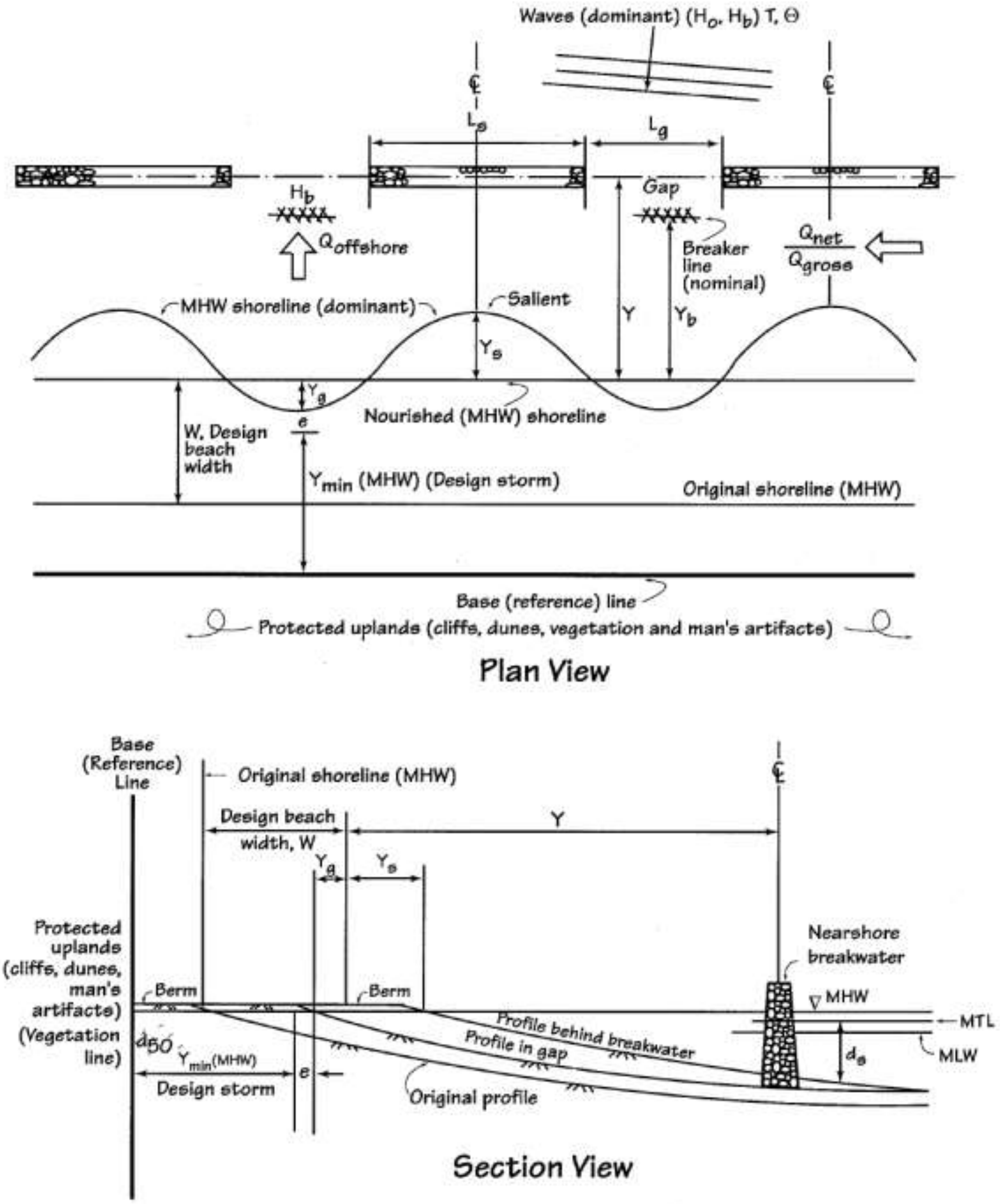

Figure 9-13 Definition schematic for nearshore breakwaters (Source: CEM, 2006)

At this location there is a natural bar situated some 220 m offshore. If this was used as a location, the length of each breakwater would be around 90 m to 110 m and the minimum gap spacing would be around 180 m. This configuration is reasonably similar to the groyne field spacing, but with offshore rather than onshore structures.

As indicated in Figure 9-13, beach nourishment would also be required. At this stage the same considerations of nourishment and dune management are proposed as set out in Section 7.9 above.

Construction of the offshore breakwater, situated in the surf zone with high wave energy could be very difficult, resulting in significantly higher costs than conventional land based systems. In addition, due to the greater water depth, the volume of rock required would be significant. For costing purposes we have assumed a standard trapezoidal breakwater configuration, emerged to around MHWS and rock placement costs 4 times the land based cost and sand transfer costing. Based on this, we have estimated a construction cost of between $10,000 and $16,000 per linear metre of shoreline.

The proposed works would have a significant visual and natural character effect and there is a risk that the structures may act to focus longshore flows, increasing the potential for shoreline erosion. As a result progressing through the consent process with this approach is likely to be difficult.

While this approach may provide medium to long term protection, additional sand top-ups or crest raising of the offshore breakwaters may be required if sea level rise accelerates as predicted. It will be important to ensure that any initial design was done taking into account potential modifications that may be required.

9.11 New technologies

Many non-traditional ways to armour, stabilize, or restore the beach including the use of patented, precast concrete units, geotextile-filled bags, and beach dewatering systems have been tried in the field. Their success depends on their stability during storm events and durability over the economic, design life. The following identify a range of approaches that have been discussed in previous submissions for Ocean Beach.

9.11.1 Submerged surf/coastal protection reefs

A submerged reef is a structure located offshore designed to induce wave breaking. Submerged reefs can exist in many different configurations and be built from a variety of different materials. Coastal protection can occur with increased wave sheltering and by a modification of the wave direction to shore, reducing longshore drift gradients and encouraging sand deposition in the lee of the structure. An advantage of these systems over conventional offshore breakwaters is that they are typically submerged and do not create a visual obstruction.

An example of a concept design for a reef is included in Figure 9-14. These structures are built from geotextile bags and often formed on land then towed out to sea, positioned and filled. There has been much analysis and debate on the success of the existing reefs, built offshore at Mt Maunganui, Opunake, Narrowneck (QLD) and Bournemouth (UK), with some issues identified in their performance as a recreational surf break and concerns for recreational swimmers landward of the reef. At this location the potential for amplifying flows along the existing trough would also need to be carefully evaluated. Detailed modelling and assessment would be required to evaluate their effectiveness. Land based works would also be required to manage the dunes, similar to that described in Section 9.3 as well as beach nourishment by sand transfer as described in Section 9.5.

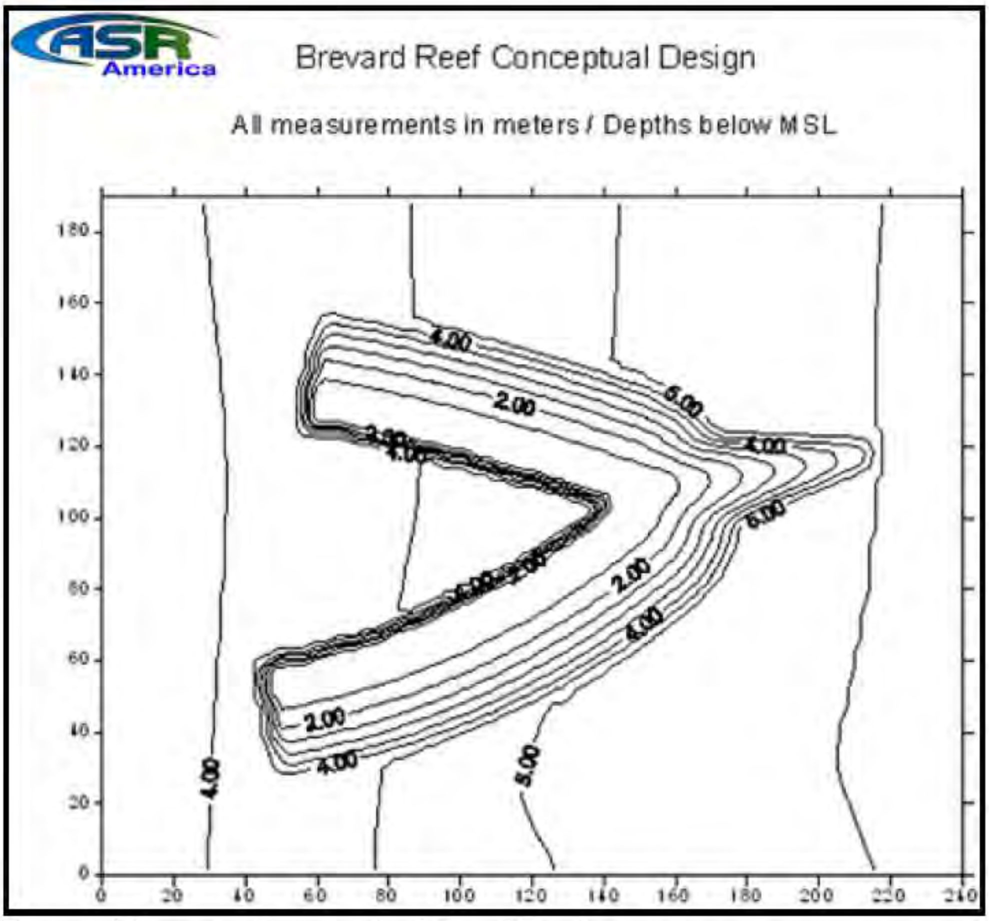

Figure 9-14 Concept reef design for Brevard County (Source: ASR, 2008)

Actual design and construction costs of the reefs cannot be accurately determined until a detailed design study has been performed. However, comparing other reef costs as shown in Table 9-1 and taking into account the high energy environment, unit costs are likely to be in the order of $300/m^3$ to $450/m^3$. For the purposes of this costing study a reef volume of 6,000 m^3 and a unit rate of $375/m^3$ has been assumed. There is considered to be considerable construction risk for submerged reefs constructed from sand-filled geotextile bags in this high energy environment.

It is likely that more than one reef would be required to stabilise the shoreline along the central and western end of Ocean Beach. For the purposes of this study, three reefs are assumed to be required, each one providing protection to some 600 m of shoreline. The indicative costs for this approach range between $10,000 and $16,000 per linear metre of shoreline.

Table 9-1 Costs for existing offshore reefs (Source: ASR, 2008)

Project/year	**Volume (m^3)**	**Cost (NZD)**	**Unit rate ($/$m^3$)**
Mt Maunganui, NZ (2005-2008)	6,500	$1.5M	$230/$m^3$
Opunake, NZ (under construction)	4,800	$1.4M	$290/$m^3$
Boscombe Reef, UK (under construction)	13,000	$6.1M	$470/$m^3$

There is likely to be strong opinions raised during the consent process both for and against offshore structures and good verification and assessments provided for the proposed design. The consenting risk is identified as being significant.

The submerged reef approach may provide medium to long term protection, although additional sand top-ups or crest raising of the offshore reefs may be required if sea level rise accelerates as predicted and these may be costly. It will be important to ensure that any initial design was done taking into account potential modifications that may be required. There is a risk that the structures may act to focus longshore flows, increasing the potential for shoreline erosion.

9.11.2 Beach face dewatering

Beach face dewatering by lowering the groundwater table along the coastline began in Denmark in the early 1980s, by accident. After installation of a filtered, seawater system for a seaside aquarium, it was discovered that the sandy beach width increased where the beach parallel, longitudinal pipe intake was buried beneath the surface. Patents were obtained by the Danish Geotechnical Institute (DGI) in many countries, including New Zealand.

Lowering the groundwater table is accomplished by draining water from buried, almost horizontal, filter pipes running parallel to the coastline. The pipes are connected to a collector sump and pumping station further inland. Gravity drains the groundwater beneath the beach and through the pipes to the sump and then the water is pumped from the sump. The sand-filtered seawater can be returned to the sea or used for other purposes.

Long-term, independent field monitoring is needed to learn more about the functional performance of dewatering systems. The system by itself does not produce new sand, so that its greatest contribution may be in increasing the fill life of renourished beaches. Early reviews identified that the effectiveness of the concept is yet to be convincingly demonstrated (Leatherman and Turner, 1997). More recent research suggests there is still no consensus on its effectiveness (Bowman, et al, 2007). At this stage it is considered in publications that dewatering should be regarded as experimental, rather than a proven solution to erosion management (Schwartz(ed), 2005).

No detailed costing information is available for this approach, although a web search indicated that costs are likely to be similar to a nourishment scheme. At this stage, we recommend applying the same construction cost as the beach nourishment approach (Section 9.6), i.e. construction costs of between $7,000 and $11,000 per linear metre including dune management.

It is possible that this approach might provide short term backshore erosion protection as a result of the dune-sloping and vegetation, with published information suggesting 50% success rates from previous projects. However, it is uncertain if it could provide medium to long term protection. This approach also has the potential to draining the landfill groundwater to the beach that could have significant adverse effects. Due to the new technology aspects and the risks to groundwater, we anticipate significant difficulties in progressing through to resource consent.

9.11.3 Undercurrent stabilisers

A patented ultra-low profile geotextile groynes injected with concrete (CEM, V-3-90, 2006) have also been proposed as an alternative approach to stabilize beaches. The stated purpose of these ultra-low profile groynes is as undercurrent stabilizers to reduce the speed of incoming waves, with the intention of forcing the sand to be deposited in the bank system, gradually regenerating the beach and dune.

There is little peer-reviewed published information on this technology and the US Army Corps of Engineers notes that this type of technology does not address all of the key issues raised by them.

To assess the effectiveness of these systems, it is likely that modelling will be required. While there are no detailed costings available for these systems, we are aware that working in the surf zone with the energy associated with this coast will be problematic and therefore costly. In addition, the dune grading and vegetation would also be required. However, the structures themselves are relatively low profile, so total volumes of material are likely to be less than for a conventional groyne field or submerged reef. A website identifies a pilot scheme at Flagler Beach, Florida, USA costing around NZ$3.5M per mile in 2006 (www.erosion.com), or around $2.6M per kilometre, taking into account 3% per annum increases since 2006. However, we note this project has yet to be undertaken, so costings are not proven construction costs.

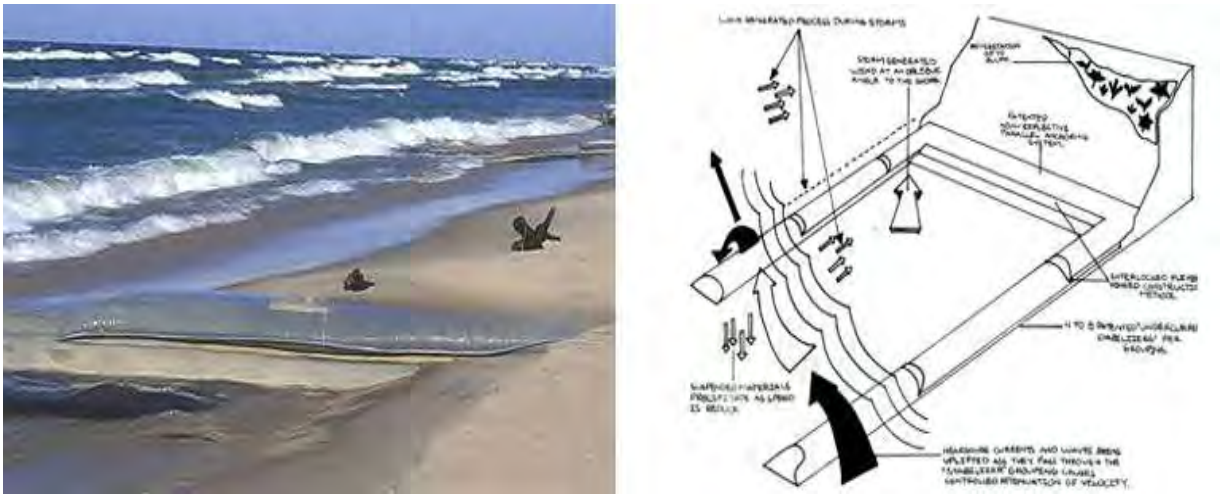

Figure 9-15 Schematic of an undercurrent stabilizer (Source: www.oceanusinternational.com)

Based on this ratio and the length of protection of 1.8 km we can guestimate the potential construction costs, including the dune management as described in Section 7.3 to be between $7,000 and $11,000 inclusive of dune reshaping and planting.

More detailed studies and investigations will be required to improve levels of understanding and knowledge, particularly on the effectiveness and robustness of the design in areas of significant wave energy, such as Ocean Beach. Consenting is likely to be complex due to the new technology and potential effects.

This approach may provide mid to long term protection to the beach, but currently it is not possible to confirm its suitability.

9.12 Summary

Table 9-2 provides an overall summary of the various approaches discussed, including our estimates of capital cost per linear metre, the options ability to provide short to long term backshore erosion management as well as the potential effects on the beach system and potential for ongoing repairs or remedial works. The difficult of the consenting process is assessed, ranging from minor to significant. The assessment of consenting risk is based on our previous experience and a review of submissions made to Council.

Table 9-2 Summary of actions

Possible Actions	Description	Approximate cost per linear metre		Potential for ongoing repairs or remedial works	Potential effect on existing beach system	Difficulty of consenting process	Provide backshore erosion management		
		From	To				Short term (0 to 10 years)	Medium term (10 to 50 years)	Long term (50 to 100 years)
Action 1	Do nothing			low	negative	nil	×	×	×
Action 2[1]	Continuation of holding pattern	$ 300	$ 600	low	neutral	minor	✓	×	×
Action 3	Dune re-shaping and vegetation	$ 4,000	$7,000	moderate	positive	minor	✓	uncertain	×
Action 4	Managed retreat	$ 9,000	$ 15,000	low	positive	moderate	✓	✓	✓
Action 5	Sand transfer	$ 6,000	$ 9,000	high	neutral	moderate	✓	uncertain	×
Action 6	Beach nourishment	$ 7,000	$11,000	high	positive	moderate	✓	✓	uncertain
Action 7a	Buried backstop wall	$ 6,000	$10,000	low	neutral	moderate	✓	✓	✓
Action 7b	Sheet pile backstop wall	$4,000	$17,000	low	negative	significant	✓	✓	✓
Action 8a	Rock revetment	$7,000	$11,000	low	negative	significant	✓	✓	✓
Action 8b	Seawall	$19,000	$30,000	moderate	negative	significant	✓	✓	✓
Action 9	Groyne field	$6,000	$10,000	high	negative	significant	✓	uncertain	uncertain
Action 10	Offshore breakwater	$10,000	$16,000	high	negative	significant	✓	uncertain	uncertain
Action 11	Submerged reef	$10,000	$16,000	high	positive	significant	✓	uncertain	uncertain
Action 12	Dewatering	$7,000	$11,000	high	negative	significant	uncertain	uncertain	uncertain
Action 13	Undercurrent stabilizers	$7,000	$12,000	high	positive	significant	uncertain	uncertain	uncertain

1. Annual cost

10 Possible options for managing Ocean Beach

This section looks at selecting from the possible actions described in Section 9 to develop a comprehensive coastal management plan for Ocean Beach providing guidance for management over the next 100 years, breaking this period down into the short (0 to 10 years), medium (10 to 50 years) and long (50 to 100 years) term.

10.1 Principles of adaptive management

Effective management of coastal hazards and the progressive changes to the frequency and scale of these hazards as a result of climate change is fundamental to maintaining sustainable and resilient coastal communities.

There are a number of possible strategies that can be used and these are illustrated in Figure 10-1. This figure shows a no adaptation approach, which is equivalent to the “do nothing” option. In this instance the level of risk of erosion, and the consequential effects, will increase over time. It also shows a precautionary approach where an action is carried out now in response to a potential future risk, which in the context of Ocean Beach, is responding to a significant erosion event and/or the additional effects of climate change. This approach can often lead to unnecessary intervention and high initial capital costs.

Key themes and characteristics of good adaptation strategies include (MfE, 2008):

- Work in partnership with stakeholders
- Understand existing risk and vulnerabilities
- Identify most adverse hazard
- Incorporate flexibility: recognise value of phased approach to adaptation
- Seek a no-regrets/low-regrets, win-win options
- Adopt a sequential and risk based approach
- Avoid options that will make it more difficult to cope with hazards in the future
- Review the effectiveness through monitoring and evaluation.

A low-regret adaptation approach is preferable and is illustrated in Figure 10-1. This type of approach seeks to avoid actions that could make it more difficult to cope with coastal hazards and climate change and risks in the future. It also provides a sequential and risk based approach to decision making as set out in the MFe (2008) guidelines. This adaptive management approach is based on identifying the current risk and the level of risk where intervention is required. It also requires an identification of the approaches required (i.e. actions) to address the risk, and when the observed risks exceed the acceptable level of risk, the action is implemented.

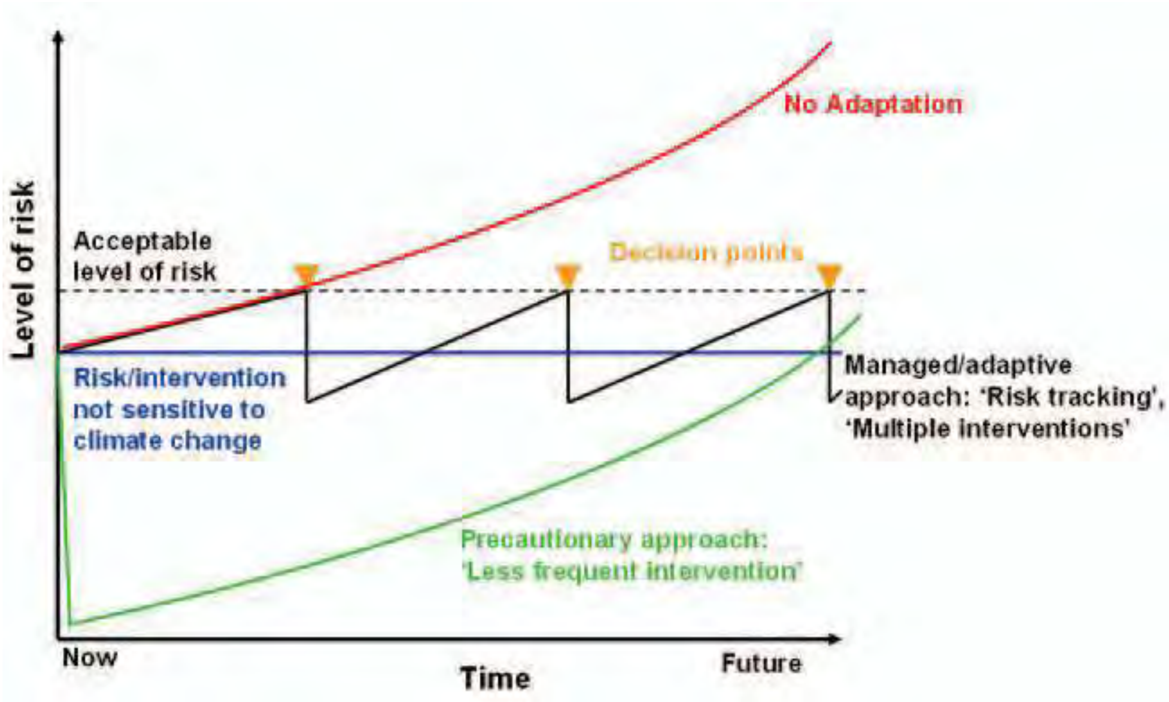

Figure 10-1 Different approaches to adaptation and their effect on the level of risk over time (Source: MfE, 2008)

10.2 Options

Taking the adaptive management approach into account, the key areas to manage extend from the eastern end of the existing St Clair seawall to around the St Kilda Surf Club (Areas 2 and 3, Figure B1, Appendix B). Area 2 and 3 comprises a narrow beach width, with over-steepened dunes, some of which front the historic landfill under Kettle Park. The actions assessment carried out in Section 9 identified that there is no simple effective solution and costs for any solution are high and many have a range of consequences and uncertainty.

It is assumed that the existing seawall at St Clair (Area 1) is managed by a separate Council process. Area 4, extending from St Kilda Surf Club to Lawyers' Head has no significant risks and can be managed by ongoing monitoring to determine if there is any change from the existing situation that may warrant a response at some time in the future. A summary table of the preferred approaches is set out in Table 10.1.

Over the next 10 years the current holding pattern approach is recommended as a reasonable management approach. At the same time monitoring of the beach and dune system should continue and a better understanding of the likely effects of sea level rise will develop with the new IPCC assessment due out in 2012/2013.

In the medium term (10 to 50 years) the preferred options to manage erosion are based on a buried backstop wall (Action 7a, refer Section 9.7.1) or managed retreat (Action 4, refer section 9.4). An indication of proposed dune toe location for managed retreat is shown in Sheets 1 to 3, Appendix A, based on a 30 m set-back from the 2007 dune toe position (i.e. 15 m storm cut and 15 m sea level rise effects). However, it is possible based on ongoing monitoring, that the continuation of the holding pattern may be effective, and this could delay the initiation of either option (i.e. the holding pattern approach may be effective for longer than 10 years).

Once either managed retreat or the buried backstop wall options are implemented, they should also provide effective management over the longer term, although the effectiveness of any option will be significantly affected by the actual rate of climate change and the consequences effect on coastal processes.

These options have an indicative cost range of between $4M and $8M over the next 10 years and from $8M to $19M in the medium term based on current costs, excluding consultancy and consenting costs.

Through the New Zealand Coastal Policy Statement (2011) and the MFE Guidance Document (2008), the preference of adaptive management is strongly preferred, with a gradual removal of assets at risk being the preferred approach over time. Both managed retreat and the buried backstop wall provide consistency with the NZCPS and the MfE Guidance Document.

Table 10-1 Buried backstop wall option to manage erosion at Ocean Beach

Time scale (years)	Area	Action	Approximate capital cost per area ($M's) From	To	Total option cost ($M's) From	To
Short term (0 to 10)	Area 1	Maintain existing wall	alternative council budget		$ 4.1	$ 8.3
	Area 2	Continuation of holding pattern	$ 1	$ 2		
	Area 3	Continuation of holding pattern	$ 3	$ 6		
	Area 4	Ongoing monitoring	$ 0.1	$ 0.3		
Medium term (10 to 50)	Area 1	Management of overtopping	alternative council budget		$ 8	$ 13
		Maintain existing wall	alternative council budget			
	Area 2	Buried rock armour backstop wall, including dune reshaping and re-vegetation	$ 2	$ 3		
	Area 3	Buried rock armour backstop wall, including partial landfill removal, dune reshaping and re-vegetation	$ 6	$ 10		
	Area 4	Dune reshaping and re- vegetation if required	$?	$?		
Long term (50 to 100)	Area 1	Possible modification of seawall	alternative council budget		$?	$?
	Area 2	Dune reshaping and re- vegetation if required	$?	$?		
	Area 3	Dune reshaping and re- vegetation if required	$?	$?		
	Area 4	Dune reshaping and re- vegetation if required	$?	$?		

Table 10-2 Managed retreat option to manage erosion at Ocean Beach

Time scale (years)	Area	Action	Approximate capital cost per area ($M's) From	To	Total option cost ($M's) From	To
Short term (0 to 10)	Area 1	Maintain existing wall	alternative council budget		$ 4.1	$ 8.3
	Area 2	Continuation of holding pattern	$1	$ 2		
	Area 3	Continuation of holding pattern	$3	$ 6		
	Area 4	Ongoing monitoring	$0.1	$0.3		
Medium term (10 to 50)	Area 1	Management of overtopping	alternative council budget		$11	$ 19
		Maintain existing wall	alternative council budget			
	Area 2	Buried backstop wall	$ 2	$ 3		
	Area 3	Managed retreat	$ 9	$ 16		
	Area 4	Dune reshaping and re- vegetation if required	$?	$?		
Long term (50 to 100)	Area 1	Possible modification of seawall	alternative council budget		$?	$?
	Area 2	Dune reshaping and re- vegetation if required	$?	$?		
	Area 3	Dune reshaping and re- vegetation if required	$?	$?		
	Area 4	Dune reshaping and re- vegetation if required	$?	$?		

11 Applicability

This report has been prepared for the benefit of Dunedin City Council with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose without our prior review and agreement.

Tonkin & Taylor Ltd

Environmental and Engineering Consultants

Report prepared by:	Authorised for Tonkin & Taylor Ltd by:
....	....
Richard Reinen-Hamill	Tim Fisher
Senior Coastal Engineer	Project Director

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Appendix A: Indication of shoreline position as a result of climate change effects

NOTES:

Landward_duneline = the most landward duneline based on historic aerial photographs, and includes 1942, 1957 and 2009 duneline features.

Dunedin_SLR_NZTM = predicted shoreline retreat due to four SLR scenarios by 2100 (0.3m, 0.6m, 0.9m, 1.5m), offset from the landward_duneline. The horizontal distance is calculated using the Komar method with intertidal beach slope of 16:1 based on beach profile data.

Dunedin_SLR_DS_NZTM = the total hazard setback including the predicted shoreline retreat due to SLR and Dune Stability (DS), offset from the landward_duneline. DS is based in the backshore height above the dune toe and the angle of repose for sand material (32 degrees or 1.8:1). The DS component is split into four zones on backshore height above the dune toe, which generally increases from west to east (8m, 10m, 12m, 14m).

Indicative Area for managed retreat = 30m setback from existing dune toe

Background Areal photograph taken in 2007 and sourced from DTek

SCALE 1:2000

0 20 40 60 80 100 (m)

LEGEND:

- Landward_duneline_NZTM
- Dune_SLR_DS_NZTM
- Dune_SLR_NZTM
- 2007_Duneline_NZTM
- Indicative area for managed retreat

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POTENTIAL SHORELINE RETREAT DUE TO SLR
(Sheet 1 of 3)

FIG. No. Figure 1.A3-1

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NOTES:

Landward_duneline = the most landward duneline based on historic aerial photographs, and includes 1942, 1957 and 2009 duneline features.

Dunedin_SLR_NZTM = predicted shoreline retreat due to four SLR scenarios by 2100 (0.3m, 0.6m, 0.9m, 1.5m), offset from the landward_duneline. The horizontal distance is calculated using the Komor method with intertidal beach slope of 16:1 based on beach profile data.

Dunedin_SLR_DS_NZTM = the total hazard setback including the predicted shoreline retreat due to SLR and Dune Stability (DS), offset from the landward_duneline. DS is based in the backshore height above the dune toe and the angle of repose for sand material (32 degrees or 1.8:1). The DS component is split into four zones on backshore height above the dune toe, which generally increases from west to east (8m, 10m, 12m, 14m).

Indicative Area for managed retreat = 30m setback from existing dune toe

Background Areal photograph taken in 2007 and sourced from DTek

SCALE 1:2000

0 20 40 60 80 100 (m)

LEGEND:

- Landward_duneline_NZTM
- Dune_SLR_DS_NZTM
- Dune_SLR_NZTM
- 2007_Duneline_NZTM
- Indicative area for managed retreat

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POTENTIAL SHORELINE RETREAT DUE TO SLR
(Sheet 2 of 3)

FIG. No. Figure 1.A3-2

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NOTES:

Landward_duneline = the most landward duneline based on historic aerial photographs, and includes 1942, 1957 and 2009 duneline features.

Dunedin_SLR_NZTM = predicted shoreline retreat due to four SLR scenarios by 2100 (0.3m, 0.6m, 0.9m, 1.5m), offset from the landward_duneline. The horizontal distance is calculated using the Komar method with intertidal beach slope of 16:1 based on beach profile data.

Dunedin_SLR_DS_NZTM = the total hazard setback including the predicted shoreline retreat due to SLR and Dune Stability (DS), offset from the landward_duneline. DS is based in the backshore height above the dune toe and the angle of repose for sand material (32 degrees or 1.8:1). The DS component is split into four zones on backshore height above the dune toe, which generally increases from west to east (8m, 10m, 12m, 14m).

Indicative Area for managed retreat = 30m setback from existing dune toe

Background Areal photograph taken in 2007 and sourced from DTek

SCALE 1:2000

0 20 40 60 80 100 (m)

LEGEND:

- Landward_duneline_NZTM
- Dune_SLR_DS_NZTM
- Dune_SLR_NZTM
- 2007_Duneline_NZTM
- Indicative area for managed retreat

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POTENTIAL SHORELINE RETREAT DUE TO SLR
(Sheet 3 of 3)

FIG. No. Figure 1.A3–3

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Appendix B: Recommended erosion management options for Ocean Beach

Time Scale (Years)	Area 1 ① St Clair Seawall	Area 2 End of Seawall to Cultural Centre	Area 3 Cultural Centre to St Kilda Surf Club	Area 4 St Kilda Surf Club to Lawyers Head
Short term (0-10)	- Maintain existing seawall	- Continuation of holding plan ($1M - $2M)	- Continuation of holding plan ($3M - $6M)	- On going monitoring ($0.1M - $0.3M)
Medium term (10-50)	- Management plan	- Buried backstop wall ($2M - $3M)	- Buried backstop wall ($6M - $10M) - Managed retreat ($9M - $16M)	- Dune re-shaping vegetation if required (?)
Long term (50-100)	- Seawall replacement modification	- Partial seawall / managed retreat (?)	- Buried backstop wall (?) - Managed retreat (?)	- Dune re-shaping vegetation if required (?)

① – Cost of works in Area 1 under alternative budget.

NOTES:
1. Aerial photo (2007) supplied by Dunedin City Council
2. Horizontal Datum is New Zealand Transverse Mercator 2000 (NZTM).

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0 100 200 300 400 500 (m)

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SCALES (AT A3 SIZE) 1: 10,000		
PROJECT No. 27226		

DUNEDIN CITY COUNCIL
OCEAN BEACH EROSION MANAGEMENT
DOMAIN RESERVE
Options

FIG. No. Figure B1
REV. 0