Managing and adapting to coastal erosion at Carters Beach

2017 review and update

Prepared for West Coast Regional Council

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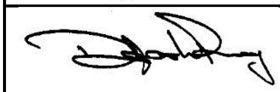	Approved for release by:	Doug Ramsay

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Executive summary

This report has been prepared for West Coast Regional Council (WCRC) to aid the decision-making processes associated with ongoing erosion problems at the village of Carters Beach. The investigations undertaken include a site visit, digitisation and analysis of historical shoreline positions off aerial photographs and review of recent relevant literature.

There is nothing to suggest the erosion rate at Carters Beach has increased since the 2006 assessment, rather, it is the awareness of the erosion problem that is increasing as the coastline advances towards community assets and the township.

The greatest driver of coastal change at Carters Beach over the past ~ century has been the construction of the Buller River training walls with the effect of massive shoreline advance to the west of the river mouth (e.g., 400 m advance at Carters Beach village). The shoreline advance reached its maximum extent in 1981, stabilised for approximately 20 years (1981-2003), but since 2003 a pattern of east-west delineation between erosion (east)-accretion (west) has appeared. This recent erosion has claimed up to 80 m of shoreline retreat at Carters Beach village, alarming the local community.

The present-day coastal erosion risk to private land in the Carters Beach community is not high because the erosion rate appears to have been slowing consistently since 2003, and it appears it will stop before reaching council/community assets (close monitoring is needed to confirm this). However, if the erosion continues and we extrapolate a high recent rate of erosion (6 m/year), and assume no change to this rate (unlikely, it appears to be slowing), it would be at least 5 years (2021) before the erosion 'scarp advances to within 10 m of the community hall (which is 60-70 m back from the current erosion 'scarp) and the risk to the council/community assets becomes critical. It would be at least 10-15 years (beyond 2027) before Marine Parade and property inland from Marine Parade would be at critical risk assuming the same erosion rate.

It is recommended that the council and community use this time to start considering their options, identify triggers and develop a management pathway should the erosion continue. To intervene too soon could be an unnecessary expense for the community, but to wait too long would be a poor decision for all and may preclude viable management options with a hasty solution more likely to have detrimental environmental impacts. The management pathway should include discussion of council and community objectives, trigger points, identification of a possible range of adaptation options, and development of pathways that meet the agreed objectives. We have presented an example adaptation pathway sequence for Carters Beach which outlines possible scenarios, trigger points and intervention options should the erosion continue. This adaptation pathway should begin now with the consultation process starting soon, rather when the risk is critical.

Underpinning this approach is a vital requirement for ongoing monitoring of the coastline, with annual interpretation of results by a qualified and experienced coastal engineer/geomorphologist.

To address the immediate public safety hazard from wave overtopping and flows into the domain reserve, we recommend that a small (1 m high, 1:3 slopes) vegetated sand dune/bund be constructed for 800 m along the reserve, set back about 30 m from the present-day erosion 'scarp on the beach face. This will not halt the erosion (if it reaches this point) but will mitigate the overtopping hazard. We recommend setting a decision point such that if erosion claims this dune/bund then it would be time to implement the next stage of the shoreline management strategy (as decided by the community and council).

1 Introduction

Coastal erosion is an issue facing numerous communities on the West Coast. This report, one of several recent reports by NIWA addressing coastal issues for the West Coast Regional Council (WCRC), addresses coastal erosion at Carters Beach, situated approximately 4 km west of Westport (Figure 1-1).

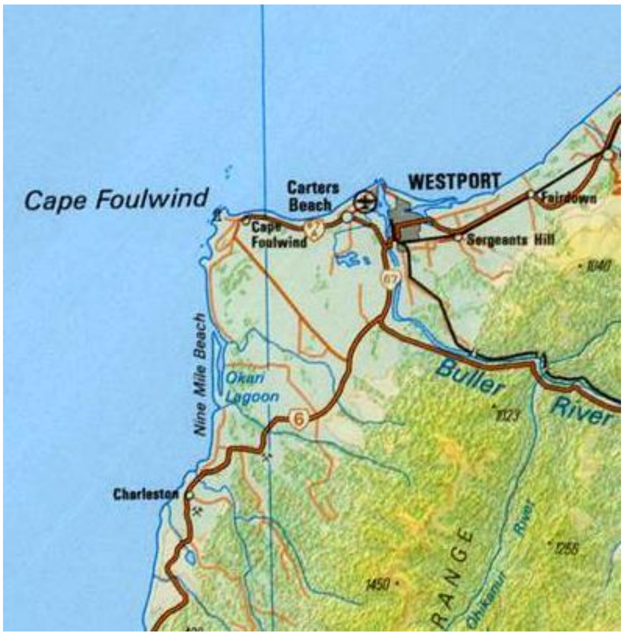

Figure 1-1: Location of Carters Beach. [Source: LINZ 1:500k series].

Coastal erosion at Carters Beach was reviewed most recently in 2006 by OCEL (OCEL 2006) for the Buller District Council (BDC). Since then, erosion of the coastline in this area has continued and threatens property and infrastructure. WCRC requested an updated assessment to identify changes to the coastal environment in the 10 years since the OCEL report was released. The assessment is intended to support WCRC, the Carters Beach community and recreational users of the beach by providing advice on a long-term strategy for management of the beach and guidance on appropriate coastal protection options.

The investigations undertaken as part of this assessment included a site visit to Carters Beach by Drs Michael Allis and Murray Hicks on the 23rd of November 2016, digitisation of shoreline positions and analysis of aerial photographs of Carters Beach/ Buller Bay and review of the OCEL (2006) report and other relevant literature since 2006, such as the West Coast Coastal Hazard Assessment (NIWA, 2012).

The work was funded by two Envirolink Small Advice Grants (MBIE Contract Numbers 1737: C01X1625 and 1738: C01X1626).

2 Site Description and Recent Observations

Carters Beach village lies to the west of the Buller River mouth and comprises the eastern shoreline of Buller Bay which extends from Kawau Point to the river mouth. Buller Bay is approximately 7 km in length (Figure 2-1) and generally north facing, presenting a gradual curve from NNE facing in the west to NNW close to the Buller River mouth.

The hinterland is generally low lying and flat, with fluvial and aeolian deposits bisected by several creeks, drainage channels and river mouth/lagoon features. Coastal terraces at elevations of 15-25 m above mean sea level (MSL) fringe the low-lying hinterland from Kawau Point to the Buller River, with historic dune deposits at the base of the terraces, some 500-1500 m inland from the present shoreline. Tertiary mudstone/sandstone cliffs rise further west in the vicinity of Kawau Point (Figure 2-1), with Cape Foulwind and the Three Steeples rocks comprised of hard granite and limestone.

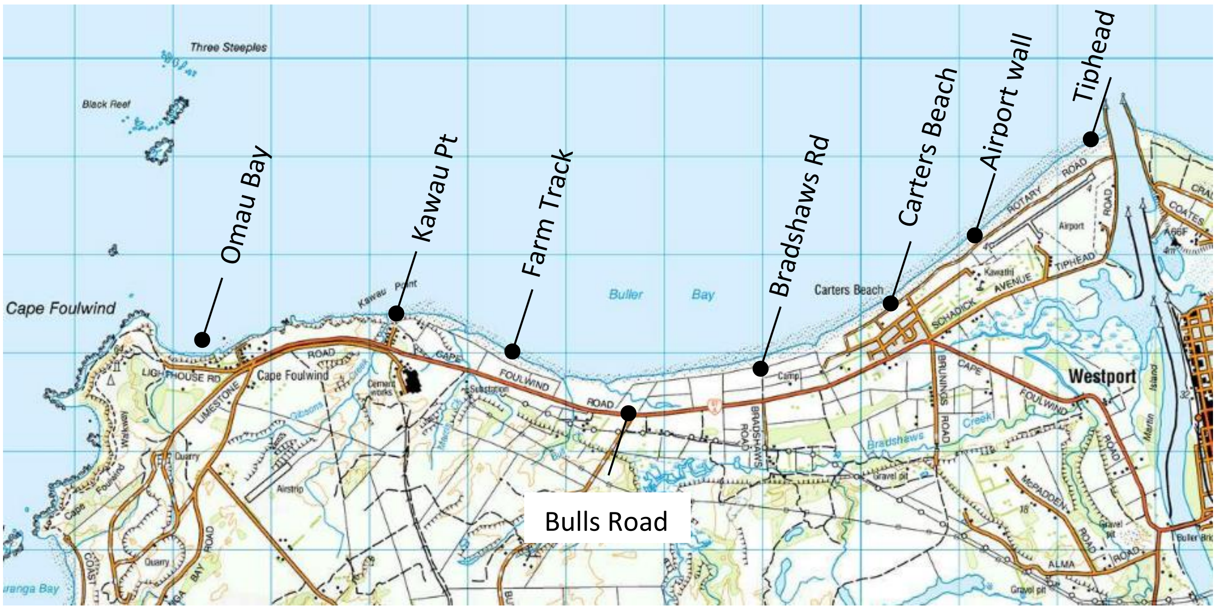

Figure 2-1: Buller Bay and Carters Beach. Text indicates beach access viewpoint. Scale: 1 km grid. [*Source*: LINZ 1:25000 series]

The beach itself comprises fine light grey sand with trace (<1%) gravels. The beach gradient is very flat with slopes between 1:30 (upper beach) and 1:100 (lower beach). The spring tide range is approximately 3.2 m, with low tide exposing a broad expanse of sand several hundred metres wide.

Within Buller Bay, the key natural drivers which determine the coastline position are i) availability of sediment for beach-building processes, ii) wave processes transporting sediment to/from the beach face on a wave-by-wave basis (i.e., cross-shore sediment transport), and iii) nearshore currents (also wave driven) driving littoral transport of sediment east/west along the coastline (i.e., long-shore sediment transport). Within Buller Bay coastal change has also been driven by human activity through the construction of the Buller River training walls, which were built to facilitate safe vessel navigation through the river mouth and into Westport Harbour (Furkert 1946, Kirk et al. 1986, 1987). The effect of the river training works is addressed in Section 3.

2.1 Site Inspection

NIWA and WCRC staff performed a walkover site inspection of Carters Beach on 23rd November 2016 (9 am to 1 pm). High tide was 1:06 pm for the Westport River mouth, offshore significant wave height was approximately 1 m from the north, and winds were moderate (< 20 km/h) from the south west. The inspection accessed the beach from several locations along the Buller Bay coastline (Figure 2-1) in a west to east sequence. Representative photographs from each location are included in Appendix A.

The present day coastal processes observed during the inspection were of both erosion *and* accretion at various sites. Generally, it appears that Buller Bay may be split into active erosion or accretion cells about a north-south line aligned approximately with Bulls Road (Figure 2-1). We observed that:

> **West of Bulls Road the beach is advancing**. At the Farm Track accessway, driftwood debris, which usually rots away after 30 years, is piled against a small relic dune line (<1 m tall) some 60-100 m from the active beach face (Figure 2-2). The intervening span of backshore has been colonised by vegetation, aiding the prograding foredune (which is advancing seaward). Between the relic dune and present-day beach, the backshore surface is notably devoid of large vegetation or substantial dune structures, with only small sandy hillocks (<1 m high) and vegetation/scrub (Figure 2-2). Between Bulls Road and Kawau Point, the beach is similarly wide, flat and prograding, although at Marris Creek mouth the low-lying hinterland is replaced by mudstone outcrops which continue west to Kawau Point. Generally in this area, the absence of well-established vegetation or dunes and presence of inland stranded driftwood debris suggests that the shoreline has been rapidly prograding at 2-3 m/year since the 1980s.

> **East of Bulls Road the beach is retreating**. All beach access locations in the eastern section of Buller Bay show evidence of active beach erosion. This evidence in the form of low erosion 'scarps, concrete debris on the beach from earlier protection efforts, many large tree stumps on the upper beach, overwash driftwood and sediment deposits on the backshore, and dead grass patches on the domain (Figure 2-3). The present erosion 'scarp is generally 1-1.5 m high at Bradshaws Road and 0.5-1.0 m high at the Carters Beach reserve. A community hall is situated at about 50 m from the present-day erosion 'scarp, while the houses and dwellings of Carters Beach village are about 120-150 m from the 'scarp. Buller District Council constructed (and extended at least once – based on aerial photos) a large rock revetment (crest approx. 4 m above beach face) to protect the northwestern flank of the Westport Airport runway from shoreline retreat. East of the airport revetment the erosion has outflanked the revetment and a notch has eroded into the coastline to within 20 m from the airport boundary fence (Figure 2-4). Discussion with community members indicates erosion in this area has been ongoing for several decades, with at least 100 m of shoreline retreat estimated.

This pattern of east-west delineation between erosion and accretion is consistent with the historic aerial photograph analysis in the following section.

Along the Carters Beach foreshore there is no indication of a developed dune system that provides sand storage and sediment exchange with the beach system. Its absence may be caused by the extremely rapid advance of the beach since river training wall construction (allowing little time for a dune to form) and may also be influenced by the prevailing wind blowing alongshore rather than onshore. However, community members also suggested mechanical (bulldozer) flattening of a backshore dune in the 1970s occurred to make way for the present-day domain reserve.

The remnants of a dune system are visible to the east of the village and in front of the golf course (where they didn't bulldoze). There appears to have been a single higher dune (<1 m tall) or narrow dune ridge, with some small sandy hillocks, but this area is now grassed for agricultural use. We suspect these dunes may have been formed during a hiatus in beach advance during the past century. These do not represent a substantial buffer of sediment to resist beach erosion and it is unclear how large this dune system may have been along the Carters Beach reserve, but its present-day absence severely limits the natural beach defences against coastal retreat.

Figure 2-2: Stranded debris within vegetated backshore area, typical of Buller Bay west of Bulls Road. View north (seaward) from 50 m from active beach face. Access from Farm Track 1.4 km east from Larsen Street. [*Credit*: M. Hicks, 23/11/2016].

Figure 2-3: Evidence of coastal retreat at Carters Beach foreshore. Accessed at Golf Links Road. [*Credit*: M. Hicks, 23/11/2016].

Figure 2-4: Erosion notch outflanking eastern end of airport revetment. Access from Rotary Road. [*Credit*: M. Hicks, 23/11/2016].

2.2 Community monitoring

The community has regularly documented coastline changes along the Carters Beach shoreline by measuring the retreat rate and photographing the erosion events. Several times between November 2016 and April 2017, waves have spilled over the beach crest, depositing swathes of driftwood debris and causing sea water to locally pond in areas 10-30 m inland from the beach crest (Figure 2-5). An exceptional wave event was reported to cause water to rush across much of the domain reserve[1], ponding in the low-lying areas next to Marine Parade, as seen in Figure 2-6.

These overwashing events are typical of a rapidly prograding coast (or formerly prograding coastlines that are now retreating – as at Carters Beach). They are part of the natural land-building process through the wave-by-wave deposition of sediment on the backshore which gradually builds up hinterland elevation in time. Wind-blown deposits are also a key part of the land-building process.

The most recent rates of erosion are based on direct measurements of the erosion 'scarp at three positions along the Carters Beach domain reserve as recorded monthly by concerned community members. From 12/12/2016 to 06/04/2017 the average (over the 3 sites) 'scarp retreat was 1.97 m, which may be extrapolated to an annualised rate of 6.2 m/year.

Figure 2-5: Debris and ponding in the Carters Beach domain reserve after 16 January 2017 wave overtopping event. [*Credit*: C. Cooper, 16/01/2017].

[1] http://www.nzherald.co.nz/nz/news/article.cfm?c_id=1&objectid=11783718
https://www.pressreader.com/new-zealand/the-press/20170118

Figure 2-6: Sea water ponding in the Carters Beach domain reserve after 16 January 2017 wave overtopping event. Note Marine Parade at right. [*Credit*: C. Cooper, 16/01/2017].

3 Shoreline position analysis

3.1 Shoreline records

The positions of historical shoreline at Carters Beach were digitised into a georeferenced framework (ArcGIS) from previous reports (OCEL 2006), council aerial photographs (BDC, WCRC) and satellite photographs (Google Earth). All shorelines are archived on NIWAs project drive and may be retrieved if required.

All shorelines were mapped into New Zealand Transverse Mercator (NZTM) projection on New Zealand Geodetic Datum 2000 (NZGD2000). The coastal images were manually georeferenced by matching multiple (5 or more) control points on each image, the ArcGIS software then automatically scaled, rotated, translated and de-skewed the graphical information (i.e., the maps or aerials) to match the geographical coordinate system (i.e., NZTM).

The relevant coastal line (vegetation line or MHWS) on each Google Earth, LINZ survey or Council photograph was then manually identified and digitally traced in the NZTM coordinate system by an experienced coastal scientist. The OCEL (2006) shorelines were re-digitised by manually tracing and digitised the georeferenced shorelines from the 2006 report figures, thereby ensuring consistency with the OCEL (2006) results (and assumes that the shorelines in the OCEL report have been rectified and digitised to a similar accuracy).

The recorded shorelines correspond to either vegetation-edge lines (being the upper extent of the active beach face where sand remains static for sufficient time for vegetation to take hold), the MHWS survey line as per cadastral surveys delineating land from sea (LINZ), or erosion ‘scarp surveys which are assumed to correspond to a line of collapsing vegetation.

The accuracy of the shoreline records are limited by the clarity of the digitised image or survey data (i.e., the age of the record). We estimate an average beach-wide shoreline accuracy of +/-5 m for pre-1990 shorelines with improving accuracy for the more recent shorelines (+/- 1 m) and better resolution of the manual erosion ‘scarp surveys by BDC (<0.5 m). The modern improvement in resolution ties into the observed rate of shoreline change (i.e., old records have poor resolution but large shoreline changes, new records have improved resolution and capture smaller shoreline changes). Those records selected were of suitable scale to provide adequate detail and resolution, and to adequately capture the key coastal changes and trends.

The resulting dataset contained 22 dated partial shorelines for Carters Beach from the Tiphead to Kawau Point (Figure 3-1). The earliest complete shoreline fix is dated 1898, with an earlier partial shoreline east of the Carter Beach township from 1868. The most recent complete shoreline is dated 2015, although there is a partial survey of the erosion ‘scarp in 2016. Note that OCEL (2006) predominantly focused on the Carters Beach village shoreline, but valuable new insights into the coastal processes in Buller Bay were obtained during this current investigation from observations in the western portion from Bradshaws Road to Kawau Point.

The digitised shorelines are presented in Figure 3-1 and illustrate the massive changes in shoreline position since town development began at Westport in the mid-late 1800s.

The mapped shorelines were intersected with eight cross-sections aligned approximately at right angles to the beach (i.e., onshore-offshore) along common geographic markers such as roads and pathways, as shown in Figure 3-1. The position of beach at the time of each survey was then compared along each cross-section, giving a history of the approximate shoreline position at each cross-section location. This shoreline history is shown in Figure 3-2, and is superimposed with the river training wall construction periods.

Note that all shorelines are presented as offsets from the 2015 shoreline position, as this was the most recent complete shoreline record. The offset is the distance inland (negative) or seaward (positive) from the 2015 reference shoreline), e.g., shorelines shown as "-50 m" are 50 m inland from the 2015 position, while shorelines 50 m seaward from the 2015 position are shown as "+50 m".

These long-term records allow interpretation of the shoreline change in the context of phases of shoreline advance and retreat.

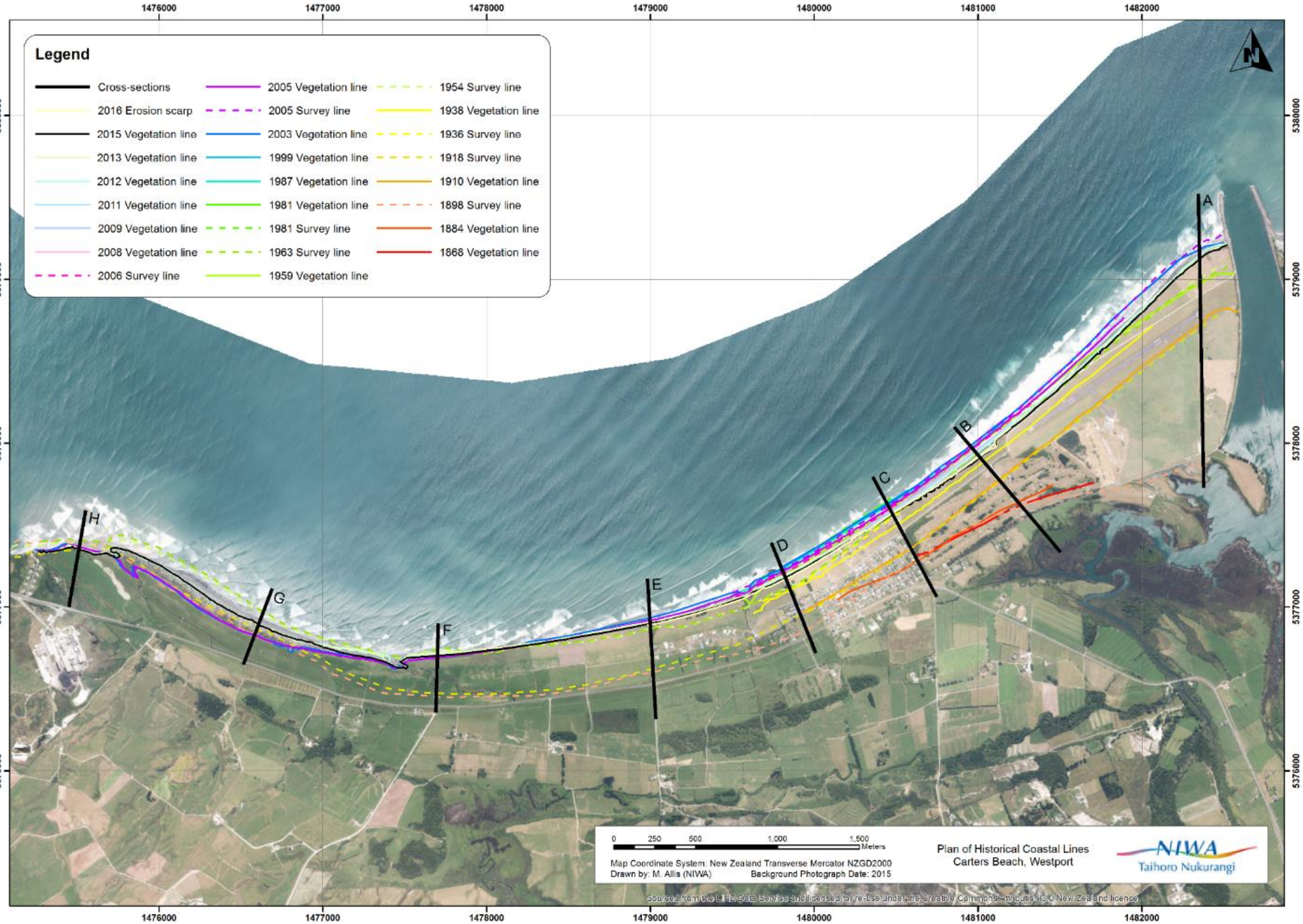

Figure 3-1: Carters Beach historical shoreline positions. Bold black lines (A-H) locate cross-sections analysed for historical trends. Note obliquely-breaking waves angled to drive an eastward littoral drift along entire shore. Coordinate system NZTM. [*Credit*: NIWA; Image sources: Google Earth, OCEL (2006), BDC, WCRC.]

3.2 Bay-wide shoreline change

The greatest driver of coastal change throughout the available records has been the construction of the Buller River training walls to facilitate safe vessel navigation through the river mouth and into Westport Harbour. The river training walls were initially constructed in 1886, were extended throughout 1913-1920, again in 1931, and were most recently extended to equal lengths (approximately 1690 m) in the 1960s where they remain today (OCEL, 2006).

The effect of the training wall construction has been a massive advance (Figure 3-1) of the shoreline to the west of the river mouth (e.g., Carters Beach township) as easterly littoral drift was stalled against the river training walls, capturing sediment which would otherwise be swept east and north along the coastline. This pattern is repeated with additional beach advance occurring after each wall construction period (Figure 3-2). The net land area gained within Buller Bay because of the training walls construction is in the order of 300 ha (3 square kilometres).

Going east to west, the notable points indicated from Figure 3-2 are:

- Adjacent to The Tiphead (Cross-section A, Figure 3-1) the shoreline advanced 1350 m from 1898 to 2005 (+12.7 m/year) but has since retreated by 100 m to 2015 (-10.1 m/year). Note that Gibb (1978) recorded advance rates up to +21.88 m/year from 1880-1919.
- In the vicinity of Carters Beach village (Cross-sections C and D, Figure 3-1) the coastline advanced about 400 m from 1898 to 1981 (+4.1 m/year). This shoreline appeared to stabilise from 1981 to 2003, with small (<10 m) changes during this time. However, since 2003 the beach has retreated 70-80 m to its present position (-2.2 m/yr).
- 1 km west of Carters Beach village at Bradshaws Road (Cross-section E, Figure 3-1), the shoreline advanced 330 m from 1898 to 2003 (3.1 m/year), but since 2003 the shoreline has retreated 40 m (-3.2 m/year) to its present position.
- 2.2 km west, at Bulls Road (Cross-section F, Figure 3-1), the maximum shoreline advance was to 300 m from 1898 to 1963 (+4.4 m/year). Since then the shoreline has experienced 40 m retreat (1963-2005) followed by 20 m advance (2005-2015) to its present position.
- 3.2 km west, at the Farm Track (Cross-section G, Figure 3-1), the maximum shoreline advance was to 150 m from 1898 to 1954 (+2.6 m/year). Since then the shoreline has experienced 170 m retreat (1954-2003) followed by 80 m advance (2003-2015) to its present which is only 60 m seaward of the 1898 position.
- Kawau Point (Cross-section H, Figure 3-1) has seen few changes to shoreline position, which is a consequence of its mudstone cliff outcrops. The beach at the toe of the cliffs moved less than 60 m since 1898, with phases of accretion (1919-1954) and erosion (1954-2015). At present, the Kawau Point shoreline is about 50 m further inland than its 1898 position.

The overall effect of the training wall construction has been for substantial land building across the wider Buller Bay, with the maximum seaward advance reaching 1350 m in the east and reducing to approximately 0 m at the western limit of Kawau Point. The majority of this shoreline advance occurred up to 1981, occurring in spurts following stages of training wall construction. About 20 years after the final wall extension the shorelines on the eastern side of Buller Bay stabilised for approximately 20 years (1981-2003) but since then shoreline retreat has commenced and continues today. Note that the western half of the beach has limited data from 1963-2003 so any stabilisation pattern is not clear. Since 2003 a pattern of east-west delineation between erosion (east) and accretion (west) has appeared, confirming observations from the site inspection.

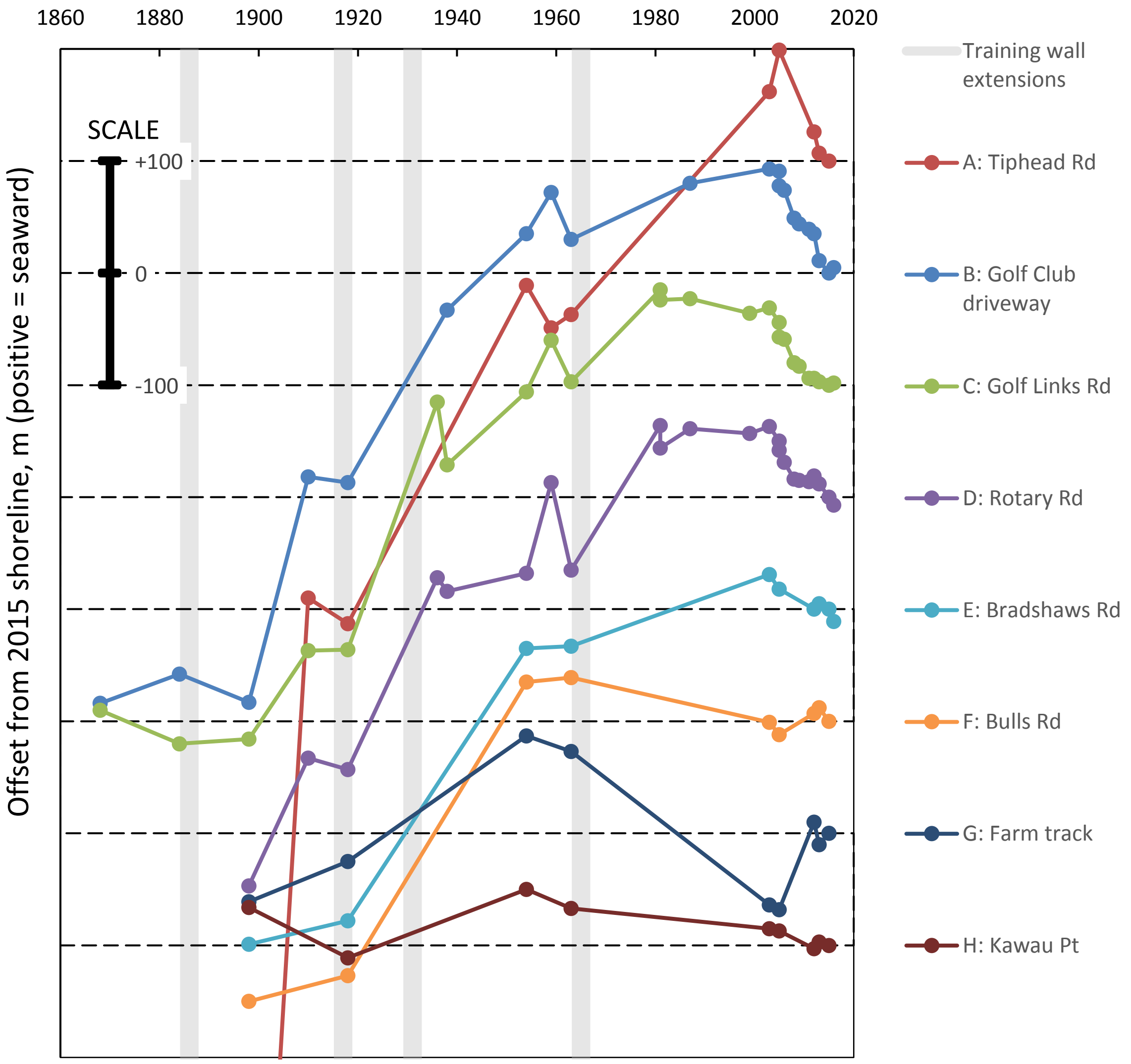

Figure 3-2: Historical shoreline positions at cross-sections within Buller Bay. Offsets are with respect to 2015 shoreline position for each cross-section. A rising line indicates shoreline advance (sediment accretion); a falling line indicates retreat. Lines separated by 100 m for plotting clarity (thus the scale bar, drawn for cross-section B, should be moved up or down to align its zero with the 2015 point on the other cross-sections). Cross-sections located on Figure 3-1. Grey bars indicate phases of training wall construction.

3.3 Recent changes at Carters Beach

Since 2003 the trend in shoreline position at Carters Beach (Golf Links Road to Rotary Road) is that the year-on-year retreat distances are decreasing, i.e., the rate of erosion is decreasing, which suggests the beach system is approaching a newer and more stable configuration. This decrease is exemplified Figure 3-3, as the most recent trend (2003-2016) has a concave shape, suggesting a less-active retreat state. However, this slowing of coastal retreat may also be a temporary effect as the former treeline/root systems, re-exposure of the historic protection works, or BDC rock protection around the Airport, could also have contributed to reduce erosion rates over this period.

There is nothing to suggest the erosion rate at Carters Beach has increased since the 2006 assessment (OCEL 2006), rather, it is the awareness of the erosion problem that is increasing as the coastline retreats towards urban development. While up to 80 m of beach has been lost since 1980, the shoreline analysis shows the erosion rates have been reducing in the vicinity of Carters Beach since 2003 (Figure 3-3).

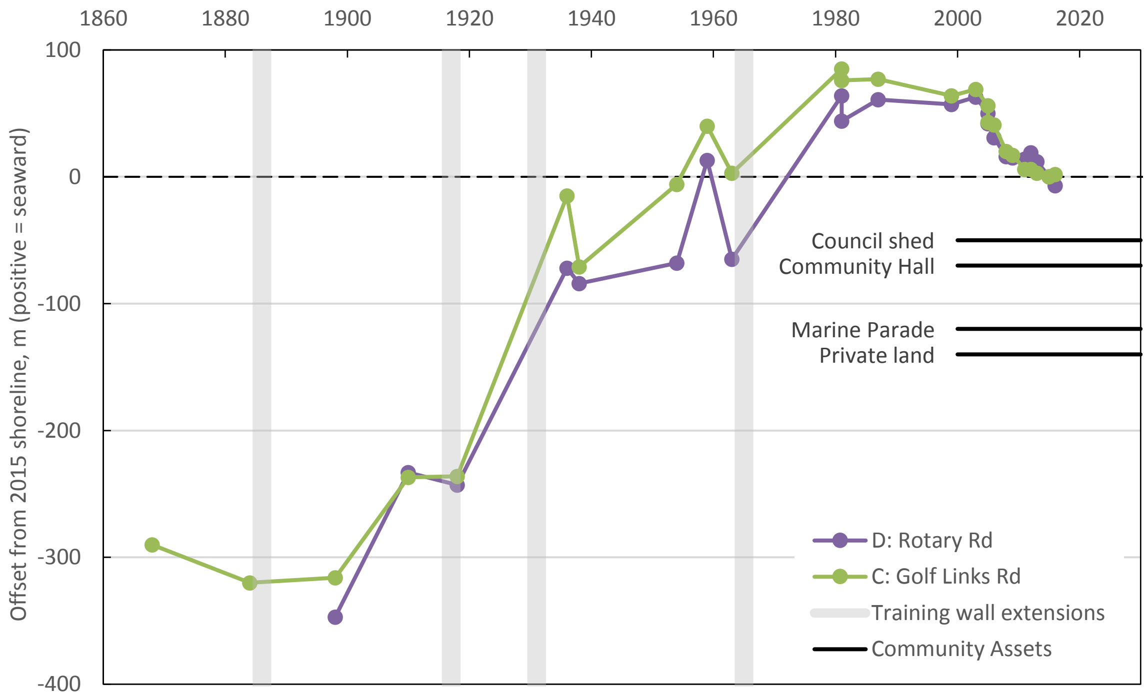

Figure 3-3: Historical shoreline positions along Carters Beach as offset from 2015 shoreline position. See Figure 3-1 for cross-section locations within Buller Bay. Vertical grey bars indicate phases of training wall construction. Black horizontal lines show offsets of assets and features relative to 2015 shoreline.

3.4 Cause of the erosion

The nature of the relatively fast growth seaward (see Figure 3-2) following the construction of the river training walls was such that the accreted land was flat and low in elevation. It had thus not had an opportunity to establish a dune system that allows a storage buffer of sand to accommodate short-term demand of sand under storm conditions, and during transient imbalances between longshore sand transport potential and supply, at a position that will allow recovery of sand under more benign wave conditions. Consequently, the beach system is more prone to larger lateral changes in position in response to minor changes to wind, wave and sediment inputs.

Several possible causes for the recent erosion trend have been considered (OCEL 2006), including changes to harbour dredging patterns, the river training works, vegetation failure during storm erosion, regional changes to sediment supply, and changes to wind patterns (but only using a 10 year record). OCEL (2006) conclude that there is not one singular identified cause for the present erosion issues at Carters Beach.

3.4.1 Preliminary assessment

A 10 year record of wind from Westport Airport is of insufficient length to couple changes to wind climate to the observed changes in the Carters Beach shoreline, particularly since the main driver of littoral transport is the incident wave climate, rather than the local wind climate. Longer-term patterns of wind/wave fluctuations remain a possible cause for the erosion.

Fortunately, NIWA has meteorological-oceanographic models which have been used to hindcast the wind and wave conditions for the entire New Zealand region from 1957 to 2002. Our preliminary analysis used the Wave and Storm Surge Prediction (WASP) model's sites close to Buller Bay (within 10 km offshore) (Gorman et al. 2010, Gorman and Bell 2011). This record of wind-generated waves encompasses the accretionary 1950s-1980 period along with the 1980-2003 'stable' period but ends before the 2003-present erosion phase.

We considered that a systematic change to beach state (erosion or accretion) should relate to variations in long-term longshore transport over cycles of years to decades - which should be captured in the WASP record.

To test this theory we applied the Ashton and Murray (2006) formula for longshore transport potential at three representative sites along Buller Bay. The sites correspond to the beach orientation in the western, central and eastern portions of the beach. This model calculates the potential for longshore sediment transport (LST) from the waves approaching the coast at oblique angles. The oblique wave approach typically observed at Buller Bay (e.g., wave patterns in Figure 3-1) is a consequence of the prevailing south-westerly waves refracting around Cape Foulwind and essentially running *along* the beach rather than *into* the beach. The Ashton and Murray (2006) approach is a simplification of the factors in Buller Bay (e.g., three dimensional refraction and headland sheltering from Cape Foulwind) however, it is suitable to identify temporal changes in the LST potential along the bay.

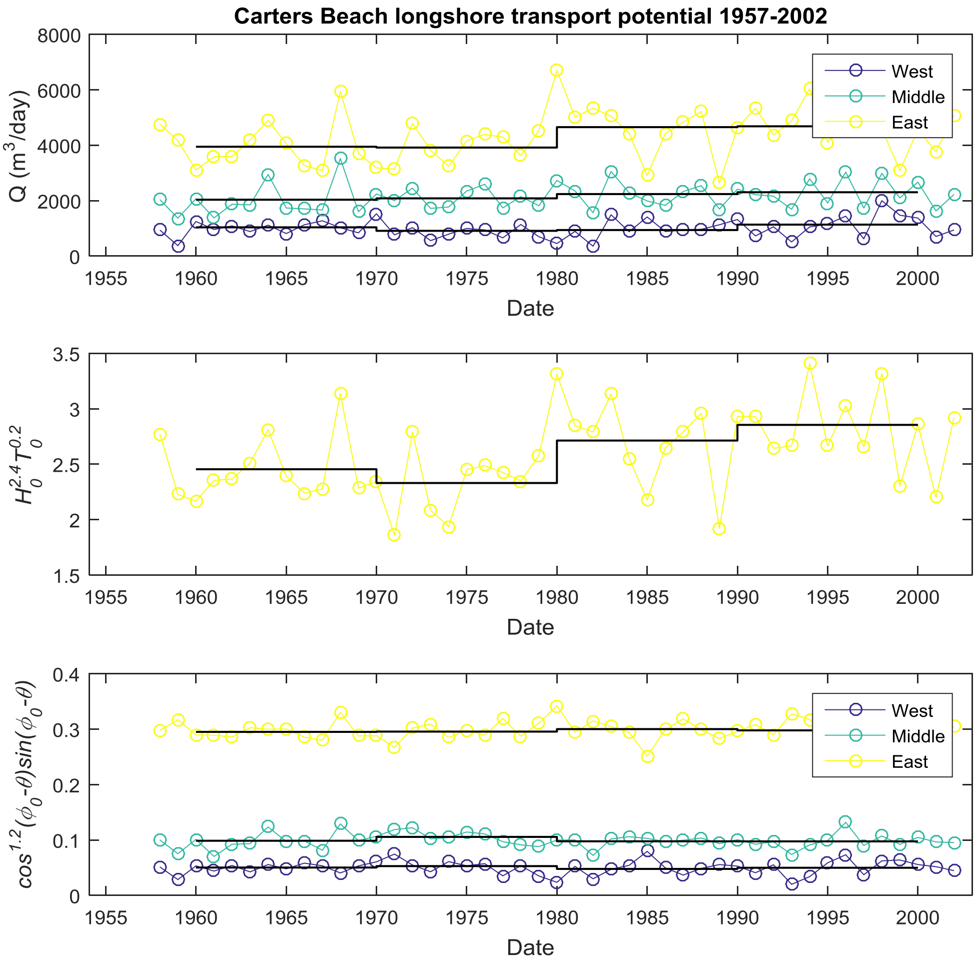

Figure 3-4: Preliminary analysis of longshore transport potential *Q* (m^3/day) and contributions from wave energy and wave direction at three sites in Buller Bay. [Top] annual (coloured lines) and decadal (black line) average of daily *Q* at each site in Buller Bay. [Middle] annual (coloured line) and decadal (black line) average of daily wave energy contribution to *Q*. [Bottom] annual (coloured line) and decadal (black line) average of daily wave direction contribution to *Q*. Wave data from WASP record and using Ashton and Murray (2006) equations. [*Credit*: NIWA]

Figure 3-4 (top) illustrates the daily-average and decadal-average LST potential at each Buller Bay site. The results show a 10-15% step-change increase in LST centered around 1979/1980 for the eastern beach site only (i.e., Carters Beach area). Such a shift in LST has the potential to swing a beach away from an accretionary phase towards a stable or eroding phase.

Figure 3-4 (middle) illustrates that the cause of the LST shift appears to be aligned with a change in incident wave energy (largely determined by wave height, shown as the $H_0^{2.4}T_0^{0.2}$ term in the Ashton and Murray equation) as there is not an obvious swing to incident wave direction at any site (shown as $\cos^{1.2}(\phi_0-\theta)\sin(\phi_0-\theta)$ where ϕ_0 is the breaking wave crest angle and θ is the shoreline orientation) around this time (Figure 3-4, bottom). The effect of increased wave energy is more pronounced in the eastern portion of the Bay, i.e., Carters Beach to the Tiphead, due to its increased exposure to the higher wave energy.

This long-term shift in the longshore transport potential on the eastern side of Buller Bay suggests that a multi-decade cycle in the wave climate may be responsible. Around New Zealand there are positive correlations to higher waves with the shorter cycles of the El Niño-Southern Oscillation[2] (ENSO, 2-7 years) and Zonal Wave-number-3 pattern[3] (ZW3, days to <2 years) (Godoi et al. 2016). However, there has been a longer-term increase to wave height around New Zealand from 1979-2008 (Coggins et al. 2015), and the longer-term (~20 year) trends for positive phases of the Pacific Decadal Oscillation (PDO) has been shown to contribute to increasing wave height and wave period mainly in the west and south New Zealand coasts (Godoi et al. 2016). The PDO was in a negative phase from 1945/1946, swung to a positive phase from 1976/1977, and back to negative in 1997/1998. While out of phase by 2-3 years, there is a conspicuous visual correlation between the positive phases of the PDO (Figure 3-5 and the temporary checks/reversals in the historical accretion trend at Carters Beach. This is a topic of further study by the authors.

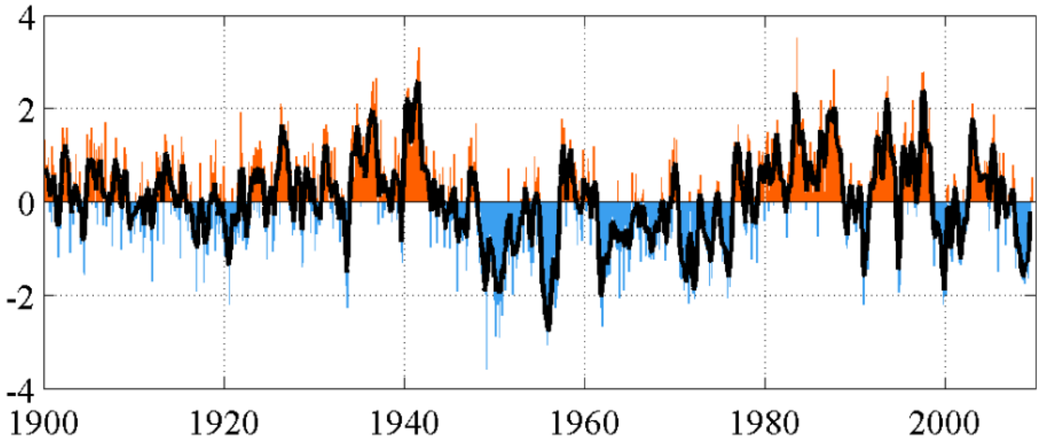

Figure 3-5: Pacific Decadal Oscillation Index 1900-2009. [Credit: University of Washington. Source: http://research.jisao.washington.edu/pdo/].

Overall, this increase in longshore transport potential on the eastern side of Buller Bay suggests that the erosion at Carters Beach is influenced by multi-decadal swings in the wave climate. The timing of the shift in LST is aligned with the transition from beach accretion to stabilisation at about 1980 seen in the shoreline position records (Figure 3-2) in the eastern half of Buller Bay and at Carters Beach. This increased demand for beach sediment coupled with the absence of any buffering dune system is believed to be a contributor to the ongoing beach erosion. This suggests that over much of the 20th century these multi-decadal fluctuations in the Carters Beach shoreline have been masked by the dominant accretionary trend associated with the river training walls. It is only now that the beach position has reached a state of dynamic equilibrium with the training walls that we are now seeing the influence of these decadal multi-decadal fluctuations in the shoreline position.

An up to date wind/wave record is necessary to establish if another wind/wave shift has substantially contributed to the present erosion phase, and is a topic of investigation study by the authors.

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[2] The Southern Oscillation Index (SOI) has been recognised for its influence on atmospheric conditions all over the world. It is characterised by sea surface temperature anomalies which are primarily observed over the equatorial region of the Pacific Ocean. It operates on interannual cycles that range from 2 to 7 years. See Godoi et al. 2015 for further details.

[3] The Zonal Wave-number 3 (ZW3) is a quasi-stationary planetary-scale pattern in the atmosphere which significantly impacts the sea ice, sea level pressure, wind and geopotential height fields on daily, seasonal and interannual periods, particularly at midlatitudes of the Southern Hemisphere. See Godoi et al. 2015 for further details.

Independent of the cause of the erosion phase, the community and councils are faced with managing the impacts of these shoreline fluctuations.

3.5 Future shoreline changes

Predictions of the future winds and wave directions are generally unable to define wind and wave direction with sufficient resolution to predict when this current retreat phase will end, nor can we accurately predict how much more shoreline retreat will occur. However, underlying any regional changes to wind and waves is an increase to baseline mean sea level caused by climate change. The current national policy[4] is to anticipate sea-level changes out to 2120 (100 years). In brief, the current national guidance[5] suggests that long term (to 2120) sea-level rise could range from 0.55 to 1.35 m (or higher), relative to MSL averaged over the period 1986–2005.

The implications for Carters Beach are that over the next 100 years, the rise in sea level is expected increase the erosion likelihood and overtopping frequency at Carters Beach as the beach system responds to these higher sea-levels. The level of protection provided by the natural defences (and any engineered defences) will reduce as sea-level rise. In the case of Carters Beach this will take the form of the beach retreating landward.

At the same time, another implication of climate change is that the westerly wave climate is expected to become more energetic. It's unclear as to whether this will be coupled to a net swing in wave direction. However, a more energetic wave climate will continue to impact on the Carters Beach alignment in the same way that the more energetic wave conditions experienced under negative phases of the PDO caused retreat of Carters Beach.

[4] New Zealand Coastal Policy Statement (2010), Policy 24

[5] The operative coastal guidance provided by the Ministry for the Environment (MfE) is the 2008 edition of Coastal Hazards and Climate Change – A Guidance Manual for Local Government. MfE have embarked on a revision of the 2008 coastal guidance, which is due for release in the first half of 2017. The new guidance will provide different scenarios of sea-level rise to test land-use plans and projects against, to ensure sufficient flexibility is provided to avoid locking in investment or path dependency based around trying to choose a "best estimate". A spread of sea-level rise scenarios for New Zealand (draft) that are likely to be incorporated into the revised 2017 guidance based on projections for different representative concentration pathways (RCPs) by the Intergovernmental Panel on Climate Change (IPCC) in their 5th Assessment Report (IPCC. 2013) and the upper curve from projections by Kopp et al. (2014)

4 Present coastal hazard risks and management approaches

4.1 Coastal erosion

The present-day exposure of private land to coastal erosion in the Carters Beach community is not high as the domain reserve is Council owned and provides a substantial buffer to Marine Parade and the private assets landward of the road. In terms of community assets located on the reserve, the recent erosion trend since 2003 is showing a year-on-year a reduction in the erosion rate and it appears the shoreline retreat may stop before reaching council and community assets.

The assets at highest risk are the council/community facilities on the domain reserve (Figure 4-1). These are offset about 40-50 m (old shed, Figure 4-3) or 60-70 m (Community Hall, Figure 4-2) from the present day erosion ‘scarp. Marine Parade and the nearest private land are about 110-120 m from the beach along the Carters Beach domain reserve at Golf Links Road, increasing to 140-150 at Tasman Street (Figure 4-1). This is a fortuitous situation for both the community and the council, as this 50-150 m space can act as a buffer against future erosion with minimal impact on the community. This assessment assumes the old shed (Figure 4-3) could be rebuilt elsewhere without much difficulty.

Figure 4-1: Features and facilities on Carters Beach domain reserve. Measurements show distance inland from 2015 shoreline position. Between 4 and 10 m of additional retreat has occurred in the 18 months since this photograph was taken. [*Credit*: Google Earth, Imagery Date: 25/12/2015].

Figure 4-2: Community hall facilities on Carters Beach domain reserve. [*Credit*: P. Birchfield, 10/05/2017].

Figure 4-3: Old shed near community facilities on Carters Beach domain reserve. [*Credit*: P. Birchfield, 10/05/2017].

However, if the erosion persists and we extrapolate a high recent rate of erosion (6 m/year) with no change to this rate (unlikely given recent trends), it would be at least 5 years (2021) before the erosion 'scarp advances to within 10 m of the community hall and risk to the council/community asset became critical. Following the same logic, it would be at least 10-15 years (beyond 2027) before Marine Parade and inland property was at critical risk from the erosion.

This then implies that the community and council have several years to consult, discuss and produce an appropriate management strategy for the erosion. To intervene too soon could be an unnecessary expense for the community, but to wait too long would be a poor decision for all and may preclude viable management options with a hasty solution more likely to have detrimental environmental impacts.

A range of management strategies for short and long-term timeframes are discussed in Section 5, but in the meantime changes, any changes in management strategies need to informed by a routine monitoring program. (At present, BDC survey the erosion 'scarp infrequently, the community undertake some quarterly monitoring along three cross-sections and Google Earth infrequently capture satellite photography).

We suggest the local 'scarp and shoreline monitoring programmes should continue and be supplemented with regular aerial photographs. We suggest annual collection and assessment of satellite imagery (these can be sources very cheaply either as new collection or recent archive imagery - few $100s). Ground-based photographs should also be taken after key erosion events (e.g., as already done by C. Cooper). Annual interpretation of monitoring results by a qualified and experienced coastal engineer or geomorphologist should accompany the monitoring. This monitoring is essential to document changes and implement a management strategy for Carters Beach now and into the future.

Wave overtopping hazard

As seen in the January 2017 wave event (Figure 2-5, Figure 2-6 and reported in the media[6]), there is a public safety risk from waves overtopping the beach crest and casting logs and other debris into the domain reserve area. The principle cause of the wave overtopping hazard in the domain is absence of a dune system on the foreshore to restrict the wave runup and overtopping flows. Note that these overwashing events are part of the natural land-building process through the deposition of sediment on the backshore which builds up hinterland elevation.

These overtopping events are expected to occur more frequently as the beach gradually erodes (because the backshore slopes down landward slightly and so the scarp height will progressively lower) and sea-level rises. The localised ponding of water in surface depressions on the reserve is a hazard and nuisance to the community. However, the regional Coastal Hazard assessment considers the low lying properties behind the domain/sports fields are at risk of flooding during high tides/storm surges (NIWA, 2012).

While there is some time available to monitor the erosion rate and formulate a suitable erosion management option, it is suggested that some form of intervention is needed in the short term to mitigate this immediate hazard of wave overtopping and ponding in the domain.

A small vegetated dune set back from the beach face will mitigate the wave overtopping hazard and restrict water and debris from spreading inland. Such a dune is not anticipated to address the erosion hazard, being designed principally to mitigate the overtopping hazard (although, it will act as a small buffer from erosion should the erosion reach it). Figure 4-4 indicates the scale and position of this feature.

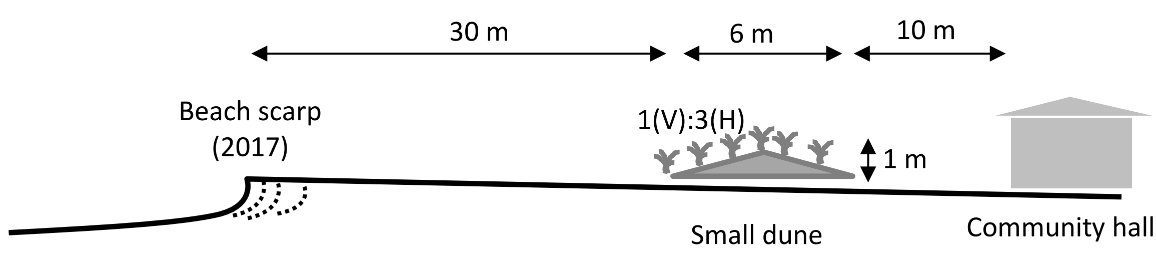

Figure 4-4: Proposed vegetated dune bund to contain wave overtopping flows. Not to scale.

[6] http://www.nzherald.co.nz/nz/news/article.cfm?c_id=1&objectid=11783718
https://www.pressreader.com/new-zealand/the-press/20170118

The dune feature should be 1 m tall, with batter slopes of 1(V):3(H) (i.e., 6 m wide) and aligned parallel to the beach face. The dune should be immediately planted with native dune vegetation to help retain the imported sediment and trap any additional wind-blown sand. Constructing with a setback at least 30 m from the beach (between the hall and beach) will allow vegetation to establish before erosion (if it continues this far) reaches the dune. This setback would require removal of the old shed and reconfiguration of the sports grounds (tennis courts and sports pitches). This will approximately align with the old low dune that still runs north from Golf Links Road, because that would prevent outflanking to the east of the domain area during overtopping waves.

The dune should extend about 800 m along the Carters Beach domain from Rotary Road to Golf Links Road. Suitable fencing is recommended to prevent vehicle damage and restricting pedestrian access to designated pathways to improve the longevity of the vegetation and the dune.

Sand and gravelly-sand is an appropriate dune material, provided it is sourced from elsewhere and NOT taken from the active beach face or dune area, and is similar to the beach material at Carters Beach. The vegetation should be salt-hardy species, such as flax and tussock grasses.

We reiterate that **this dune feature is principally to mitigate the wave overtopping hazard** and is not designed to address the erosion (although it may help a little). Any additions or changes to the dune feature should be discussed with further coastal engineering input to design and costings, based on a clear definition of the purpose and expectations for the dune feature.

5 Managing coastal change in the longer term

5.1 Adaptation pathway

An adaptation pathway is a process of managing changing levels of risk, including minimising or reducing risk where possible, and managing any residual risk. It involves a process for achieving change over time to enable people and communities to adjust to changing conditions and to minimise or reduce the risk to themselves and to property from the effects of natural coastal hazards. In essence, an adaptation pathway is a journey which involves many steps towards a place where coastal communities are resilient, i.e., to a place where communities have the capacity to adapt to climate change impacts (Britton et al. 2011).

Adaptation is complex and often involves iterative steps over time to include and give effect to community needs, legislation and environmental change. An adaptation pathway is based on a mutual understanding of the issues relating to climate change, coastal hazards and risk, and the needs of different participants. Adaptation is a shared responsibility and partnerships are critical between the community and authorities (Britton et al. 2011)[7].

The adaptation pathway for coastal change is illustrated schematically in Figure 5-1 and is detailed in Table 5-1.

Figure 5-1: Illustration of Pathways to Change – 4 steps on the coastal adaptation journey. From Britton et al. (2011, Figure 3.1).

[7] Britton et al. (2011) addresses coastal adaptation to climate change and provides guidance for a pathway to change for Councils and communities to follow when addressing and adapting to coastal erosion changes. Britton et al. (2011) refers to the national guidance manual titled *Coastal Hazards and Climate Change: A Guidance Manual for Local Government in New Zealand* (MfE, 2008) as the most comprehensive account for establishing effects of climate change and sea-level rise on coastal areas of New Zealand, and as the fundamental basis for the adaptation pathway.

Table 5-1: The 4 step adaptation pathway. From Britton et al. (2011, Table 3.1).

Step 1	**Awareness and Acceptance**	This step is about informing people within your council and your communities of the potential effects of climate change. It is also about accepting there's a problem and that further work is needed. • *Why do we need to be doing anything about coastal adaptation to climate change?* • *How much of a priority is it?* • *What are the levels of political and community awareness, and how could we enhance this awareness?* • *How are other councils addressing coastal adaptation to climate change?* • *Do we have general acceptance that we have a problem to address?*
Step 2	**Assessment**	This step is about gathering knowledge to be better informed on the scale and scope of potential effects of climate change • *What information do we need to assess how climate change might affect our local coastal communities?* • *What issues do we face?* • *Where are our most vulnerable locations?* • *What is the level of risk we are facing?*
Step 3	**Planning a way forward**	This step is about planning what needs to happen to achieve adaptation to climate change • *What is going to be our strategic and long-term approach to adaptation?* • *What are the steps required to move us in this strategic direction over time and thereby build community resilience?* • *How do we get buy-in from key stakeholders and communities?*
Step 4	**Implementation, Monitoring and Review**	This step is about undertaking the actions that have been set out in the adaptation plan developed in Step 3. It includes monitoring change over time of the environment, of information, of implementation progress and so on. The monitoring results then feed into regular reviews of the adaptation plan, in order to incrementally build community resilience to the increasing risks being faced. • *Is our plan for a strategic way forward being implemented effectively?* • *Are our communities becoming more resilient to climate change?* • *What do we need to monitor, and what are the triggers for reviewing our adaptation plan?*

When considering planning for an adaptation pathway at Carters Beach, note that the New Zealand Coastal Policy Statement (NZCPS 2010) recommends promoting and identifying long-term sustainable risk reduction approaches, including the relocation or removal of existing development or structures at risk (NZCPS 2010, Policy 27(1)(a)), and calls for focus on reducing the need for hard protection structures (i.e., rock revetments) and similar engineering interventions (NZCPS 2010, Policy 27(2)(a)).

The Carters Beach community of the West Coast is already on the journey of adaptation to long-term coastal changes. The community are:

- Past Step 1 as they are aware of the coastal erosion issues and have begun to accept that future coastal changes will impact their coastal properties.
- Passing Step 2 as information has been gathered and assessed to inform the scope, scale and timeframes of the future coastal changes and risk being faced.
- At Step 3 which is about planning what needs to happen to best adapt to coastal changes in the long term.

5.2 Planning a management pathway

This planning involves identifying options and pathways as three steps:

1. **Decide council and community objectives**. That is: consult on what values and expectations the community and councils have for the domain area now and in the long term, discuss requirements for a level of service in this area, discuss acceptable risks, discuss financial contributions, and discuss foreseeable needs for future generations.

2. **Identify the possible range of adaptation options.** Adaptation options at the coast can be described under the following groupings:

   - **Accommodate**. Adjusting existing assets by using measures that anticipate hazard risk, such as raising floor levels, providing alternative inundation pathways, requiring relocatable houses.
   - **Protect**: Holding the line using natural buffers (e.g., sand dune restoration, wetland enhancement or creation, beach nourishment) or hard structures (e.g., seawalls/barriers, groynes).
   - **Retreat**. Moving existing people and assets away from the coast in a managed way over time, or as a consequence of erosion and inundation damage after storm events.
   - **Avoidance strategies**. To stop putting people and assets in harm's way, primarily using land use planning measures and policies at regional or district level.

   In practice, a combination or sequence of these types of measures will be needed as the communities transition from increasingly affected coastal areas (retreat is inevitable in some areas on the West Coast, e.g., Granity). Preliminary assessment of these options is shown in Section 5.3.1.

3. **Develop pathways that meet the agreed objectives**. Exploring different pathways using scenarios designed to include a mix of short-term actions and long-term options. Any decisions, thresholds or milestones must be based on community-established acceptable risks.

The plan should also be adaptive so it can be implemented in stages based on how the shoreline responds over time, the community vulnerability and with new information/assessments. It should also set out the overall context and strategic directions for managing coastal areas at a large scale and draw together community aspirations.

Integral to the plan is monitoring the rate and change of the shoreline to enable effective and early response when trigger points are reached that mark a decision point when the next step of a pathway should be implemented, or whether reassessment of the objectives or the plan itself is needed, necessitating a return to the start of the decision process.

Any trigger points should be based on risk to property (e.g., how close the storm waves or erosion 'scarp get to property) rather than retreat/migration of beach features (which are more difficult to quantify). For example, we suggest an appropriate first Trigger Point may be if the erosion 'scarp reaches the fenceline protecting the new dune/bund feature.

This type of adaptation strategy with decision points means that if the beach advances seaward (accreting sediment), the planning and preparation is not wasted and may remain for when/if erosion affects valued community assets again.

5.3 Example Pathway at Carters Beach

The next steps for the Carters Beach community and council will be something like:

1. Investigate (scope, price, consent) and construct (if the council/community are prepared to fund) the small dune/bund (1 m tall, 1:3 batter slopes, 800 m long, shore parallel between the community hall and beach) to mitigate the wave overtopping hazard for domain users.

   Accept that this dune/bund may be sacrificial and is unlikely to halt the beach erosion should it encroach as far as the dune/bund.

2. Continue the programme of beach and foreshore monitoring, supplemented with annual aerial/satellite photographs and assessment.

3. Consult to define the trigger points to help define the adaptation pathway to manage the effects of coastal erosion.

Figure 5-2 below outlines a suggested adaptation pathway sequence for Carters Beach. In this diagram, we have pre-filled sections with options specific to Carters Beach (italics) to help direct the pathway and exemplify the process described above. This initial section of the pathway assumes the small dune is constructed in the near future along the Carters Beach domain (see Section 0), no further development is permitted on the domain and that shoreline movements continue to be accommodated until the next defined trigger point is reached.

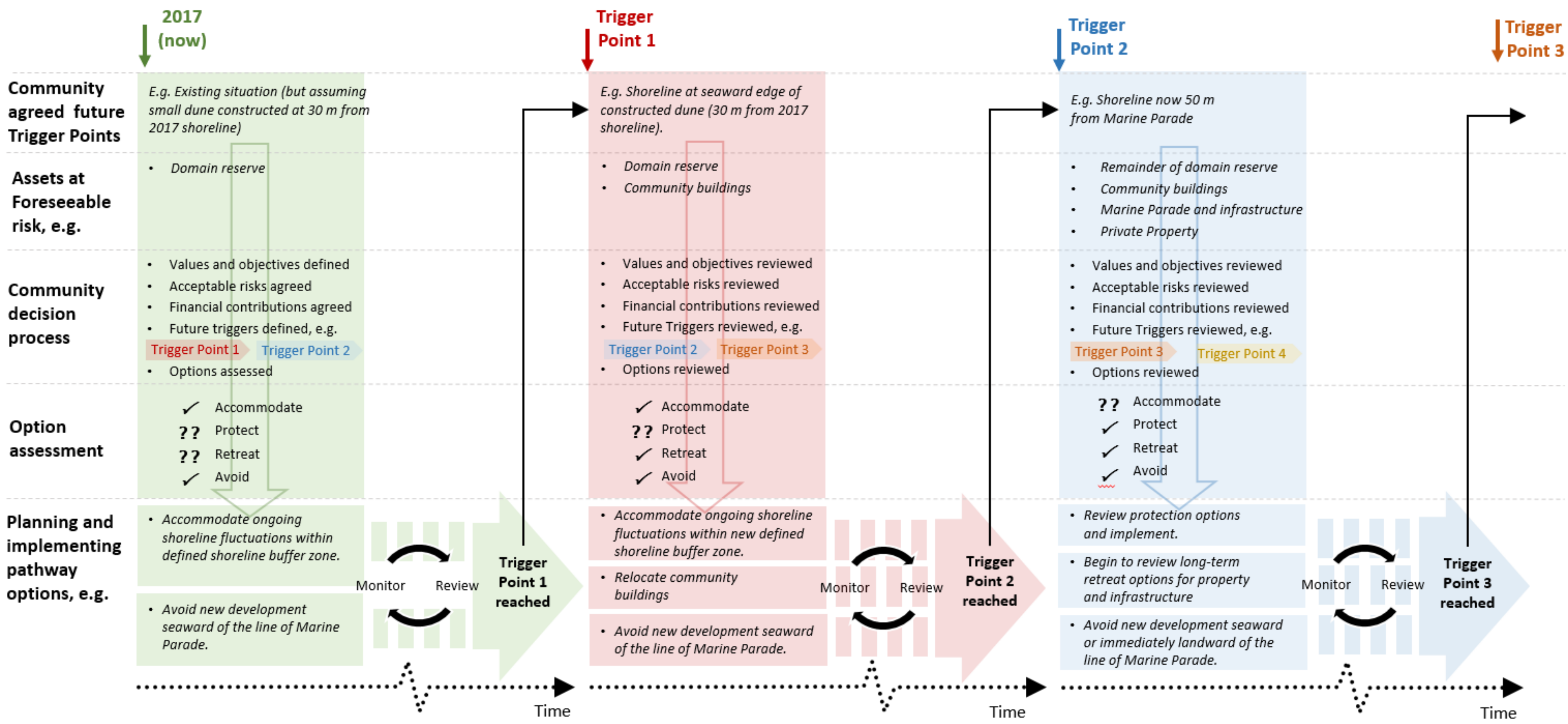

Figure 5-2: Example adaptation pathway sequence for Carters Beach. See text for full description of each step and options. Note that italics represent examples specific to Carters Beach which may be appropriate but should be reviewed by the community and council.

5.3.1 Options assessment at Carters Beach

Within the management pathway (Figure 5-2) is the stage of assessing the options which are under the groupings of *Avoidance strategies, Retreat, Avoid* and *Protect*. Here we briefly comment on each grouping to provide information for the community consultation at Carters Beach. These descriptions are not exhaustive, rather they represent a brief preview of the options and their likely applicability at Carters Beach.

- *Accommodate.* The most effective way to manage the coastal erosion hazard at Carters Beach is to allow the beach to advance and retreat naturally. This requires sufficient setback distances and sediment buffer to accommodate the shoreline position fluctuations and would usually comprise a vegetated berm, natural sand-dunes or barrier beach. At Carters Beach, the wide domain reserve could act as a buffer to accommodate reasonable erosion. The community and council need to discuss whether they accept that this space could be used to buffer the village from erosion (both present-day erosion and with climate change). If this is accepted, then enhancing this buffering (e.g., through artificial dune construction and maintenance nourishment) would aid in slowing any ongoing coastal retreat.

- *Protect.* Coastal defences such as seawalls or revetments built to 'hold the line' are often viewed as 'solutions' to coastal erosion problems. Unfortunately, such actions tend to be reactive and are rarely the most effective option in the long term. The construction of defences also leads to a false sense of security and often facilitates further development behind the structures. Ultimately, there is an expectation that such defences will be maintained *in-perpetuity,* which leads to ever increasing financial commitment to upgrade and maintain the defences. Coastal defences should only be used where property is at direct risk from storm or erosion damage, and retreating is no longer an option. Such defences should be considered transitionary, to 'buy some time' to permit a longer-term approach to reducing the property risk. Carters Beach does not have community or private assets at critical risk, so does not have immediate need to pursue a coastal defence option. However, the community should consider scenarios whereby this might become appropriate amongst other adaptation options – see Pathways plan in Section 5.3.

- *Retreat.* The option to move houses away from the coastline should not be discounted as a future option at Carters Beach as it is the most reliable way to reduce risk to people and property. However, it is not required at this stage (see Section 4.1). The community and council have time to consider scenarios when this might be appropriate, or to consider with other adaptation options - see Pathways plan in Section 5.3.

- *Avoidance strategies.* At Carters Beach, Council planning and development controls are necessary to stop putting people and assets in harm's way. It is important that both Councils (BDC and WCRC) and landowners are aware that further development seaward of the line of Marine Parade (i.e., setback about 100 m from the present-day shoreline) will be likely be impacted by coastal hazards during the lifetime of the property.

6 Summary and recommendations

There is nothing to suggest the erosion rate at Carters Beach has increased since the OCEL (2006) assessment, rather, it is the awareness of the erosion problem that is increasing as the coastline advances towards community assets and the village.

The greatest driver of coastal change at Carters Beach has been the construction of the Buller River training walls with the effect of massive shoreline advance to the west of the river mouth (e.g., 400 m advance at Carters Beach township). The shoreline advance reached its maximum extent in 1981, stabilised for approximately 20 years (1981-2003), but since 2003 a pattern of east-west delineation between erosion (eastern side of Buller Bay) and accretion (western side of Buller Bay) has appeared. This recent erosion along the eastern part of Buller Bay has caused up to 80 m of shoreline retreat at Carters Beach, alarming the local community.

The present-day coastal erosion risk to private land in the Carters Beach community is not high because the erosion rate appears to have been consistently slowing since 2003, and it appears it will stop before reaching council/community assets (close monitoring is needed to confirm this). However, if the erosion continues and we extrapolate a high recent rate of erosion (6 m/year), and assuming no change to this rate (unlikely since it appears to be slowing), it will be least 5 years (2021) before the erosion 'scarp advances to within 10 m of the community hall (setback 60-70 m) and risk to the council/community asset becomes critical (note we assume the old shed will be removed). It would be at least 10-15 years (beyond 2027) before Marine Parade and property inland from Marine Parade is at critical risk from the same erosion rate.

It is recommended that the council and community use this time to start considering their options, identify triggers and develop a management pathway should the erosion continue. To intervene too soon could be an unnecessary expense for the community, but to wait too long would be a poor decision for all and may preclude viable management options with a hasty solution more likely to have detrimental environmental impacts. The management pathway should include discussion of council and community objectives, trigger points, the possible range of adaptation options, and pathways that meet the agreed objectives. We have presented an example adaptation pathway sequence which outlines possible scenarios, trigger points and intervention options should the erosion continue. This adaptation pathway should begin now with the consultation process starting soon, rather when the risk is critical.

Underpinning this approach is a vital requirement for ongoing monitoring of the coastline, with annual interpretation of monitoring results by a qualified and experienced coastal engineer or geomorphologist.

To address the public safety hazard from waves overtopping the beach crest, we recommend that a small (1 m high, 1:3 slopes) vegetated sand dune/bund be constructed for 800 m along the domain reserve, set back about 30 m from the present-day beach face. This will not halt the erosion (if it reaches this point) but will mitigate the overtopping hazard until then. The event of erosion claiming the fence at the base of the dune/bund would be a good decision point for implementing the next stage of a shoreline management strategy (as decided by the community and council).

7 References

Britton, R., Dahm, J., Rouse, H., Hume, T., Bell, R., Blackett, P. (2011) Coastal Adaptation to Climate Change: Pathways to Change. *Report prepared as part of the Coastal Adaptation to Climate Change Project.*

Coggins, J.H.J., Parsons, S., Schiel, D. (2015) An assessment of the ocean wave climate of New Zealand represented in Kidson's synoptic types. *Int. J. Climatol*. No. 36: 2481-2496. DOI: 10.1002/joc.4507.

DOC (2010) *New Zealand Coastal Policy Statement*. Department of Conservation.

Furkert, F.W. (1946) Westport Harbour. *Transactions of the Royal Society of New Zealand*, Vol. 76, Part 3: 373-402.

Gibb, J.G. (1978) Rates of coastal erosion and accretion in New Zealand. *New Zealand Journal of Marine & Freshwater Research,* Vol.12, No. 4: 429-456.

Godoi, V.A., Bryan, K.R., Gorman, R.M. (2016) Regional influence of climate patterns on the wave climate of the southwestern Pacific: The New Zealand region. *J. Geophys. Res. Oceans*, 121: 4056–4076, doi:10.1002/2015JC011572.

Gorman, R.M., Bell, R.G. (2011) "What's happening to New Zealand's wave climate?". *Presentation at the New Zealand Coastal Society Annual Conference,* Nelson, 6-9 November, 2011.

Gorman, R.M., Bell, R.G., Lane, E.M., Gillibrand, P.A., Stephens, S.A. (2010) "New Zealand wave climate – simulating the past and future". *Presentation at the New Zealand Coastal Society Annual Conference,* Whitianga, 17-19 November, 2010.

IPCC (2013a) Climate Change 2013: The Physical Science Basis. *Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge: Cambridge University Press. Retrieved from www.ipcc.ch/report/ar5/wg1/

Kirk, R.M., Hastie, W.J., Lumsden, J.L. (1986) Sedimentary processes operating around a river mouth port, Westport, New Zealand. *New Zealand Journal of Marine and Freshwater Research,* Vol. 20: 337-347.

Kirk, R.M., Hastie, W.J., Lumsden, J.L. (1987) Harbour entrance morphology and sediments at a river mouth port, Westport, New Zealand. *New Zealand Journal of Marine and Freshwater Research,* Vol. 21: 689-691.

Kopp, R.E., Horton, R.M., Little, C.M., Mitrovica, J.X., Oppenheimer, M., Rasmussen, D.J., Strauss, B.H., Tebaldi, C. (2014) Probabilistic 21st and 22nd century sea-level projections at a global network of tide-gauge sites. *Earth's Future,* 2(8): 383–406. Retrieved from http://dx.doi.org/10.1002/2014EF000239.

Ministry for the Environment (MfE) (2008) Coastal Hazards and Climate Change. *A Guidance Manual for Local Government in New Zealand*. 2nd edition. Revised by Ramsay, D., Bell, R. (NIWA). Prepared for Ministry for the Environment: viii+127.

NIWA (2012) Review of West Coast Region Coastal Hazard Areas. *NIWA Client Report* CHC2012-081, prepared for the West Coast Regional Council: 65. Revised December 2015.

OCEL Consultants NZ Ltd (2006) *Review of Coastal Erosion - Carters Beach*, for Buller District Council.

Appendix A Beach photographs

Figure A-1: Omau Bay looking west towards Cape Foulwind (access from Domain Road). [*Credit*: M. Allis, 23/11/2016].

Figure A-2: View east across Buller Bay from Kawau Point. Buller River tiphead just visible (at left – see arrow). Access from Larsen Street. [*Credit*: M. Allis, 23/11/2016].

Figure A-3: View northeast across Buller Bay towards tiphead. Buller River tiphead just visible (at right – see arrow). Access from Farm Track 1.4 km east from Larsen Street. [*Credit*: M. Hicks, 23/11/2016].

Figure A-4: View northwest past Kawau Point towards the Three Steeples. Access from Farm Track 1.4 km east from Larsen Street. [*Credit*: M. Allis, 23/11/2016].

Figure A-5: View east towards Carters Beach (trees). Access from Bradshaw's Road. [*Credit*: M. Hicks, 23/11/2016].

Figure A-6: View east from Carters Beach. Access from Golf Links Road. Tiphead visible in centre at distance. [*Credit*: M. Hicks, 23/11/2016].

Figure A-7: View west towards Cape Foulwind from Carters Beach. Access from Golf Links Road. [*Credit*: M. Hicks, 23/11/2016].

Figure A-8: View southwest towards Carters Beach from airport revetment wall. Access from Rotary Road. [*Credit*: M. Hicks, 23/11/2016].

Figure A-9: View southwest towards Carters Beach from tiphead at mouth of Buller River. Access from Tiphead Road. [*Credit*: M. Allis, 23/11/2016].