Rivermouth-related shore erosion at Hokitika and Neils Beach, Westland

Prepared for West Coast Regional Council

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Executive summary

This report provides advice on two hazard situations relating to rivermouth processes: one at Hokitika, the other at Neils Beach in South Westland. At Hokitika, the main issue relates to the southward deflection of the Hokitika River outflow channel behind a bar rooted to Sunset Point on the north bank. This mouth configuration has raised concerns about potential effects on flooding in the Hokitika River estuary and on erosion of the Hokitika foreshore. At Neils Beach, a phase of shore erosion over the past five years or so is consuming the single foredune that protects the Neils Beach settlement and airstrip. Advice was sought on the cause of this erosion and potential mitigation options.

At Hokitika, the river mouth bar is unlikely to significantly affect flood levels in the estuary because the additional river path to the south side of the river mouth is not substantial compared to the direct outlet path, while a large flood could be expected to quickly enlarge the outlet channel. The present mouth configuration is, if anything, facilitating the northward wave-driven transfer of sand and gravel from the river mouth area to the Hokitika foreshore. The eroding span of shore on the north side of the Sunset Point carpark is eroding primarily because it is indented back from the line of the two robust seawalls, which causes end-effects.

The recommendations at Hokitika are to:

- do nothing about the river mouth bar immediately, but monitor its form and if it grows substantially from its present state consider an artificial cut past Sunset Point
- link the robust seawalls at Sunset Point and fronting Hokitika town centre together into a continuous wall along a smooth line, with the linking section built to the same standard as the two existing end segments.

At Neils Beach, aerial photograph evidence over the past 40 years indicates a history of erosion and accretion cycles. The beach fronts the western side of the Arawhata River delta, which has a form determined by the interplay of coastal and river processes. When the delta 'bulges' seaward following Arawhata floods, the shoreline configuration is such that beach-grade river sediment is spread west by waves from the northerly quarter, stocking up Neils Beach, while the bulge also acts as a 'soft groyne' that hinders the eastward transfer of sediment off Neils Beach when waves arrive from the prevailing westerly quarter. At other times, though, coinciding with periods of relative dominance by coastal processes, the river mouth bulge is 'planed-off' and the river outlet is forced eastward, causing Neils Beach to erode. The recent erosion phase is such a case, and was likely triggered by a combination of a very large wave and longshore transport event followed by two years of benign river flows and low sediment delivery. Field evidence suggests that the Arawhata River has now returned to its more normal position closer to Neils Beach, with some renourishment occurring from river sand and gravel and less sediment "leaking" eastward. However, it will likely require some years or even decades for the beach sediment stocks to rebuild again. In the meantime, the shore remains vulnerable to further erosion from storm waves. In the long-term, the shore will continue to experience erosion/accretion cycles, with erosion exacerbated by rising sea levels.

The recommendations at Neils Beach are for a staged response by:

- importing sandy gravel from the Arawhata River channel to build a protective bund (and at the same time building up beach stocks)

- monitoring the position of the shoreline fronting Neils Beach and the configuration of the Arawhata River outlet, and, if the outlet migrates east, cutting a new western outlet
- developing long-term plans for relocating assets beyond the zone at hazard from the erosion/accretion cycles, allowing also for the effects of future sea-level rise.

1 Introduction

This report responds to a request from West Coast Regional Council (WCRC) to provide brief advice on two hazard situations, one at Hokitika, the other at Neils Beach in South Westland (Figure 1-1). At Hokitika, the main issue related to the southward deflection of the Hokitika River outflow channel behind a bar rooted to Sunset Point on the north bank. WCRC were concerned about the potential effects of this situation on flooding and on erosion of the Hokitika foreshore. At Neils Beach, a phase of shore erosion over the past 5 years or so is consuming the single foredune that protects the Neils Beach settlement and airstrip. WCRC sought advice on the cause of this erosion and potential mitigation options.

Both sites were inspected in October 2015.

The work was funded by an Envirolink Small Advice Grant (Contract 1625-WCRC147).

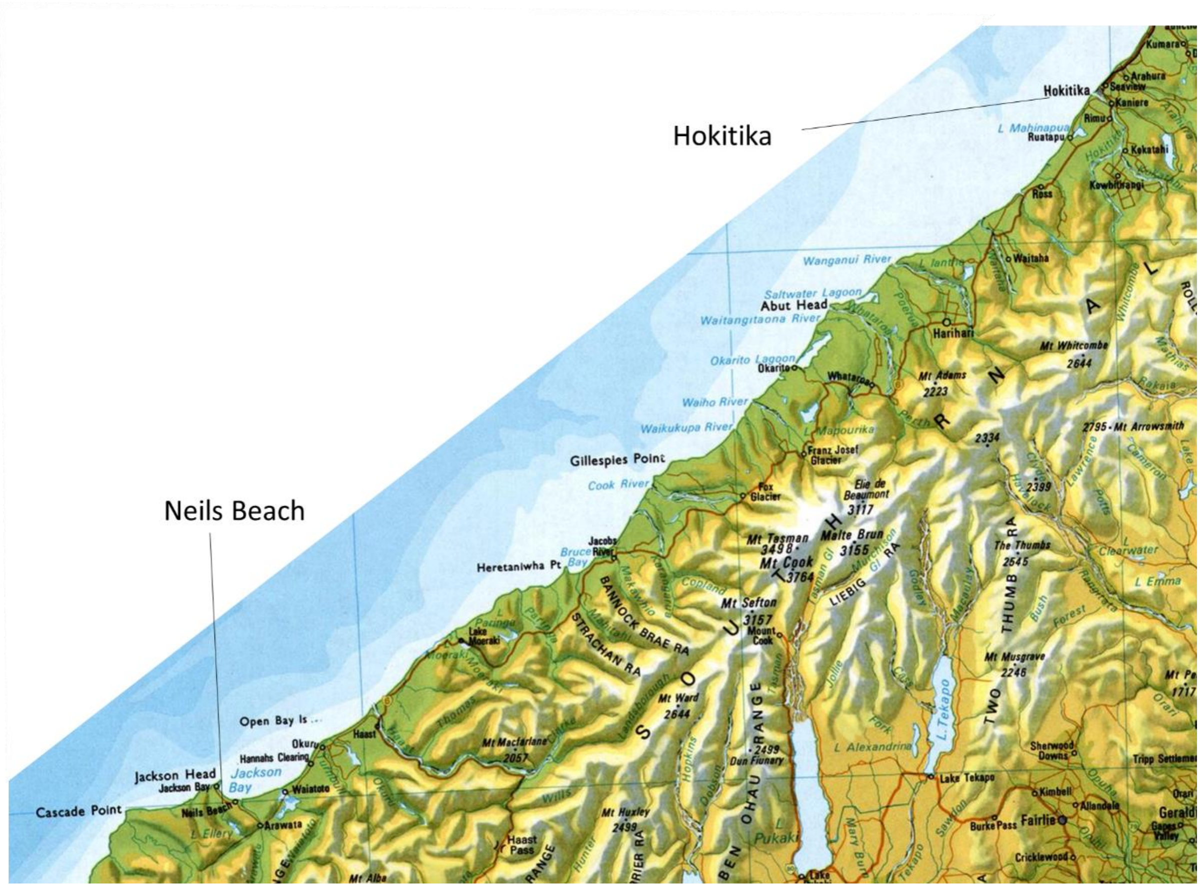


Figure 1-1: Map of Westland locating Hokitika and Neils Beach. Map sourced from MapToaster.

2 Hokitika River mouth

2.1 Background

During 2015, a period lacking any major floods, the Hokitika River mouth has migrated south, resulting in a long sandy gravel bar which is partially blocking the river mouth. The Hokitika community have expressed concern about this situation to WCRC, wondering if the partially blocked mouth might increase the river flooding risk at Hokitika if a major flood flow did occur. There are also concerns with foreshore erosion at Sunset Point, immediately north of the river mouth. Erosion at this location has worsened recently, and WCRC wondered if that may be due to a lack of sediment transported to this area – possibly related to the bar migration situation.

WCRC sought advice on these two (possibly related) issues to help them decide what, if any, action would be required to deal with these situations. In particular, advice was sought on the utility of an artificial cut through the bar immediately beside Sunset Point to encourage the river outflow to swing north.

The work involved inspection of aerial photographs of the river mouth provided by WCRC, a field visit on 28 October 2015. Oral advice was provided to WCRC on that date, and this is summarised herein.

Figure 2-1: Bars partially blocking Hokitika River mouth, September 2015. View is to southwest. Note obliquely-approaching waves. Photograph supplied by WCRC.

2.2 Field inspection

The Hokitika River mouth was inspected on 28 October 2015 around midday, part way through an incoming tide. A moderate westerly swell was breaking, driving a northward longshore current. Key observations were:

- The main river outflow channel remained deflected to the southern side of the river mouth.
- The river mouth bar was a double bar (including an inner and outer bar as in Figure 2-1 and Figure 2-2). Wave swash was collecting in the runnel between these bars and was flowing into estuary (Figure 2-2). This had cut a channel some 10 m wide hard against the rip-rap at the tip of Sunset Point. This conveyed more flow as the tide-level rose. The outer bar appears to have been swept inshore off the broad area of river mouth shoal.
- The seaward side of the Sunset Point carpark was fronted by a broad sandy-gravel beach / foreshore bar that connected to the outer bar across the river mouth. Waves broke obliquely all along the outer bar and this beach and drove a northward drift of beach sediment – thus waves were working sediment off the river mouth bar towards Hokitika (Figure 2-3).
- Immediately north from the “Tambo” at Sunset Point, erosion was occurring in the span of shore between the two well-formed seawalls (Figure 2-4). The span of poorly-constructed rip-rap seawall immediately north of the “Tambo” had experienced partial collapse and wave overwash. The rip-rap in this segment was smaller and placed lower than the more robust segments of seawall. Driftwood litter and sand patches on the berm and road behind this section indicated recent overtopping by waves (Figure 2-5). The worst erosion was to the unprotected segment of shore (Figure 2-6). This suffers from “end effects”, receiving additional attack from waves reflected/funnelled off the ends of the seawall segments. The whole eroding span of shore is indented relative to the enclosing segments of robust seawall. This creates an additional focus for wave energy.
- Further north, past the Hokitika town centre, the beach was sandy and reasonably wide, having accreted over the past year and beginning to lap over the new seawall (Figure 2-7).

2.3 Situation analysis

2.3.1 River mouth bar

My assessment is that the river mouth bar is not likely to significantly affect flood levels in the Hokitika River estuary. This is because the additional river path to the south side of the river mouth is not substantial compared to the direct outlet path. Also, a large flood could be expected to quickly enlarge the outlet channel. Moreover, the small swash channel running hard beside Sunset Point (if it remains) would be enlarged during a flood.

Figure 2-2: View south from Sunset Point lookout at Hokitika River mouth on 28 October 2015. Note double bar and swash collecting in runnel between bars and flowing into estuary.

Figure 2-3: View north from Sunset Point lookout at Hokitika River mouth on 28 October 2015. Note beach/foreshore-bar in front of carpark and obliquely-breaking waves driving northward longshore transport.

Figure 2-4: View north from "Tambo" at Sunset Point on 28 October 2015. Note terminus of foreshore-bar extending past Sunset Point, erosion in un-protected span of shore between rip-rap seawall segments, finer rock size and lower height of seawall adjacent to eroding section, and channel conveying swash to eroding section.

Figure 2-5: View east towards Sunset Point access road on 28 October 2015. Note driftwood litter and sand patches on grassy berm and beside road, placed by wave overwash.

Figure 2-6: View north along eroding, unprotected span of foreshore between seawalls on 28 October 2015. Photo taken just north of "Tambo".

Figure 2-7: View north along Hokitika town foreshore on 28 October 2015. Note reasonably well-stocked sandy beach lapping rip-rap seawall.

In the unexpected case of the bar appearing to impede a flood, a machine could be deployed to assist a channel to open past Sunset Point.

Based on the observed situation, there was a "healthy" northward longshore transport stream operating, transferring beach sediment from off the river mouth bar to the foreshore past Sunset Point – thus the bar configuration did not appear to be having any detrimental effect on beach sediment supplies to the Hokitika foreshore. Indeed, it probably assists this, since the long bars provide a consistent and substantial breaker angle that drives the longshore transport past Sunset Point (whereas wave/current interactions and offshore bars associated with a river outflow directly past Sunset Point will tend to interrupt the longshore transport).

Monitoring water levels in the estuary at the Hokitika wharf would inform on the extent of outflow impedance provided by river mouth bars at Hokitika – since an impeded outflow will reduce the range of the tide. Such a record, once compiled over several years, would become increasingly valuable.

2.3.2 Foreshore north of Sunset Point

The eroding span of shore is eroding primarily because it is indented back from the line of the two robust seawalls, which causes end-effects. The fix is to link the seawall at the carpark in a continuously line with the longer seawall extending along to the town centre. The link section should be built to the same standard as the two end segments. Without this, the erosion will likely continue, possibly even resulting in waves cutting off the Sunset Point Road.

2.4 Recommendations

The recommendations for the Hokitika River mouth issues are as follows:

- Do nothing about the river mouth bar immediately, but monitor its form and if it grows substantially from its present state consider an artificial cut past Sunset Point. Leaving it as-is would appear to assist sediment transfer onto the Hokitika foreshore.
- Monitor water levels in the estuary at the Hokitika wharf on an ongoing basis to inform on the extent of outflow impedance provided by river mouth bars. After some years, the record will provide useful guidance on how to respond to situations like the present one.
- The robust seawalls at Sunset Point and fronting Hokitika town centre should be joined into a continuous wall along a smooth line, with the linking section built to the same standard as the two existing end segments.

3 Neils Beach

3.1 Background

Neils Beach, between Haast and Jackson Bay, is a small community consisting of roughly 15 homes and an airstrip. The settlement is located just west of the Arawhata River mouth, and over the last 5 years has experienced severe erosion of 3-4m/yr. This erosion has consumed some 20 m of foreshore and protective dune, and has advanced to the state where continued shore retreat may expose dwellings, roads, and the SW end of the airstrip to damage or loss by erosion or by increased risk of coastal flooding. Options such as protective structures (e.g. a sea-wall) have been considered, but WCRC first sought a better understanding of the underlying cause of the recent spate of erosion, and then some advice on an appropriate mitigation response.

3.2 Geomorphic setting

From a geomorphic perspective, Neils Beach spans the western side of the Arawhata River delta in Jackson Bay (Figure 3-1). Waves arriving dominantly from the West refract around Jackson Head and break at an angle to the shore, driving a net north-eastward longshore drift of beach sediment that appears to be sourced mainly from the Arawhata River. Most of the Arawhata sediment is moved north-east, but occasional wave events from the northerly quarter will drive a reverse drift from the river mouth back onto Neils Beach.

To the north-east of the river, a series of backshore beach ridges (Figure 3-1) indicate how the wave-distributed river sediment has built out the Jackson Bay shoreline over the past 8000 years or so (i.e., since sea-level stabilised after its last major post-glacial rise). Most likely, this shoreline advance has occurred on an episodic basis, associated with high sediment discharges from the Arawhata River following Alpine Fault ruptures.

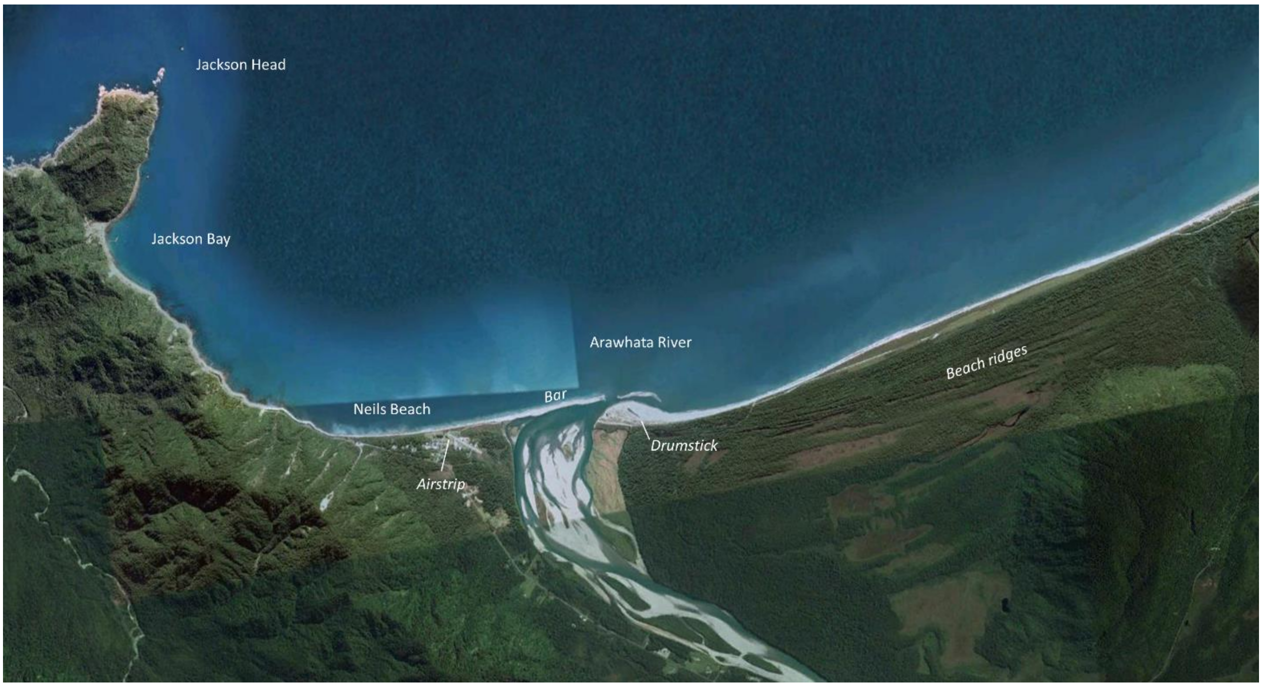


Figure 3-1: Photomap locating Neils Beach on the western flank of the Arawhata River delta. Satellite image from 9 April 2013. West is to the left.

3.3 Field inspection

The author visited Neils Beach on 29 October 2015, walking the shore between the Arawhata River mouth and the Jackson Bay road and inspecting the shore along the road to Jackson Bay wharf. The weather was fine, with a light westerly swell.

3.3.1 Observations

My main observations were:

- Active foreshore erosion was occurring from north-east of the airstrip to the Jackson Bay Road (e.g. Figure 3-2). The single sandy foredune fronting the grassy swale in front of the settlement (Figure 3-3) was severely eroded, with the eroding edge part way down the back slope of the foredune. Total loss of this dune would potentially expose the road and some dwellings to sea-flooding.
- Further west, the erosion was progressing into bush (but not threatening assets), exposing backshore features such as peat layers and swamp/swale deposits (Figure 3-4). This western shore is naturally partly armoured by a ramp of locally-sourced cobbles, with some of these having been washed by waves into the backshore bush (Figure 3-5). This shore also receives some protection against wave erosion at high tide from exposed tree roots and fallen trees.
- In contrast, within a few 100 m of the river mouth there appeared to be a relative abundance of river-sourced beach sediment, with accreting bars of fine gravel (Figure 3-6) and wind-blown sand patches.
- On the day, the longshore transport in front of the settlement was north-east (as indicated by the angle waves broke against the shore), but this reversed close to the river mouth due to the presence of the large gravel bar building from the river mouth (Figure 3-7). This was trapping sand eroded from further west along Neils Beach.
- The Arawhata River's outflow channel to the sea was located towards the western (Neils Beach) side of its delta area (Figure 3-6).

3.3.2 Assessment of beach sediment sources

Neils Beach was stocked with two types of sediment: platy, grey-brown pebbles and cobbles of meta-sandstone lithology, and finer, more well-rounded gravel of schist origin (Figure 3-8). The former became dominant, coarser, and more angular towards the west and was clearly sourced from the local gullies incised in the steep moraine slopes on the landward side of the Jackson Bay Road. The latter became dominant closer to the river and was identical to the bed-material of the river itself. We do not expect any beach sediment supply from sediment passing around Jackson Head, since the seabed deepens quickly to over 100 m by some 2.5 km offshore (Rattenbury et al. 2010). Thus the Neils Beach stock appears to be derived from very local stream/gully sources from the west and from the Arawhata River to the north-east.

Figure 3-2: Eroding foreshore of Neils Beach east of settlement. View east towards Arawhata River mouth.

Figure 3-3: Eroding grassed-over sand-dune, Neils Beach settlement. View east towards Arawhata River mouth.

Figure 3-4: Eroded, forested shore west of Neils Beach settlement. Note exposed older dune sand with soil and forest cover. View is west towards Jackson Bay.

Figure 3-5: Platy shingle wave-washed into bush, west of Neils Beach settlement. Note exposed silt beds from ancient backshore swale. View is west into Jackson Bay.

Figure 3-6: Accreting fine-gravel bar, west side of Arawhata River mouth. View is to north-east. Surf in distance marks river mouth.

Figure 3-7: Longshore transport convergence-point west of fine-gravel bars at eastern end of Neils Beach. Left photograph looks west into Jackson Bay from gravel bar; note breaker approaching from west. Right photograph looks back east to same gravel bar; note breaker approaching from east.

Figure 3-8: River and locally-sourced beach gravel on Neils Beach. Left shows mainly finer, rounded schist pebbles sourced from the Arawhata River. Right shows platy meta-sandstone pebbles and cobbles sourced from hillside gullies immediately west of Neils Beach.

3.4 Further analysis

A brief office-based analysis was undertaken to clarify the recent history of shoreline position off aerial and satellite imagery and to search for any signal in the dominating natural processes: waves (and their potential to transport beach sediment alongshore) and flows from the Arawhata River (and their delivery of beach-grade river sediment).

3.4.1 Shoreline change captured on aerial and satellite imagery

Satellite imagery of Neils Beach and the Arawhata River mouth were sourced from Google Earth, while scanned vertical aerial photographs were supplied by WCRC. Collectively, these provided a sequence from 1977 through 2013 (although some coverage of the area was only partial). The older images were georeferenced and rectified to overlie the 2013 imagery using the ArcGIS software[1]. Shorelines, defined by the edge of foreshore vegetation, were digitised on each set of imagery. Figure 3-9 shows a sequence of selected imagery with the 2013 shoreline superimposed. Figure 3-10 shows the earlier shorelines overlaid on the 2013 imagery.

Features to note are:

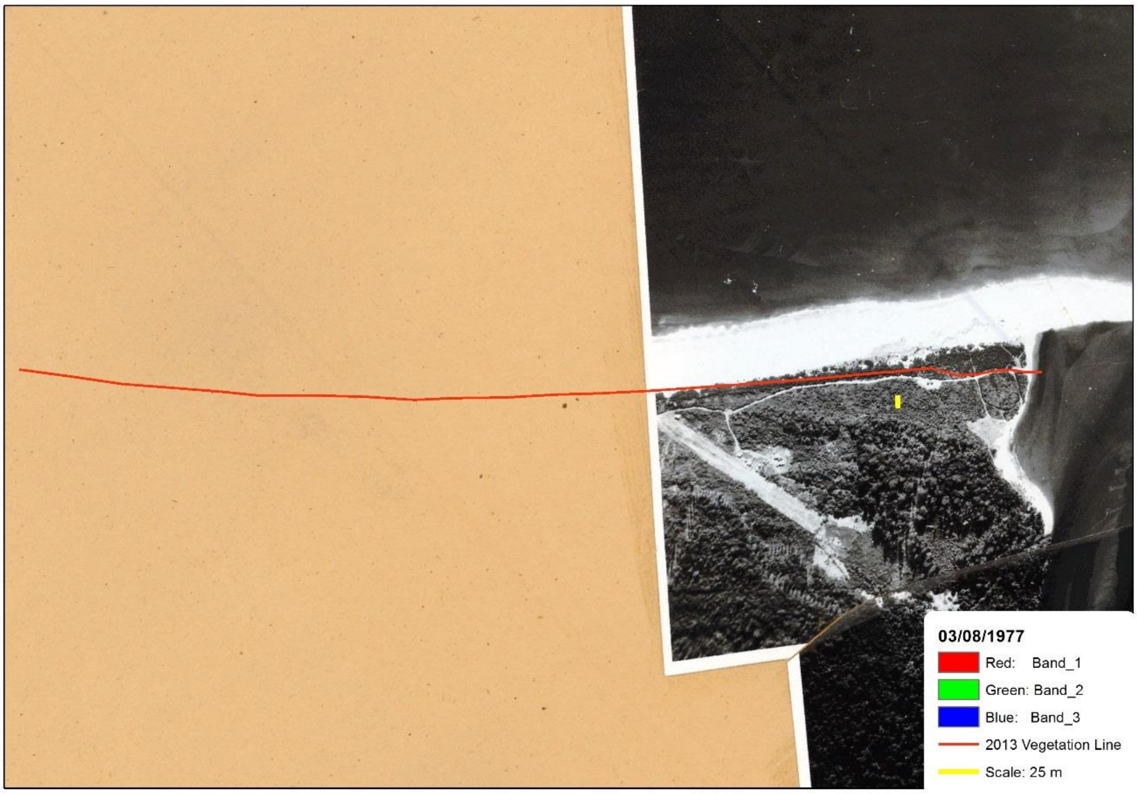
- Since 1977 (at least), the Neils Beach shoreline has experienced advance and retreat cycles. In 1977, the shore in front of the settlement was about where it is now. Between then and now it has built out by ~ 50 m and eroded away again.
- While the 1977 photo stops at the end of the airstrip, we suspect that the 1977 shore position further west may be indicated by a linear feature in the backshore vegetation on the 2013 image (marked with an "O" on Figure 3-10). Despite this erosion phase in front of the settlement in 1977, the 1977 shore was relatively accreted at the Arawhata River mouth.

[1] Checks at reference points (e.g. building corners) indicated that this rectification was accurate to 1-2 m in the area of the settlement, where there was an abundance of 'sharp' features suitable for use as reference points. It will be less accurate towards the river mouth and towards the Jacksons Bay road.

- By 95, the river mouth corner had been cut back (most likely by the large flood that occurred in 1994 – see Section 3.4.3).
- By 2003-5, however, substantial accretion (~ 50 m) had occurred all along Neils Beach.
- By 2010-11, the shore had retreated again, with a further retreat of ~ 10-15 m in front of the settlement up to 2013.
- Considerable erosion has occurred since the 2013 imagery was acquired. For example, the strip of brush visible on the grassed foredune in front of the settlement in 2013 has now been lost (marked with an "E" on Figure 3-10).
- Through the current retreat period, the Neils Beach shoreline has pivoted clockwise, with the river mouth 'bulge' having been progressively trimmed back.

Thus, the present phase of erosion is part of a multi-decadal cycle. Such cycles are typical of shorelines adjacent to wave-dominated river mouths. The imagery record is too sparse to pin-down exactly when the erosion phase began, but it would appear to be sometime between 2005 and 2010.

At a wider-scale, changes have also occurred in the configuration of the Arawhata River mouth bar and the alignment of the main river channel. In particular, from 1977 through the mid-2000s (at least when captured on aerial photographs) the mouth bar tended to bulge seaward and the river outflow tended more central or west. In contrast, since 2010 (at least) the bar has tended to run straighter and the river outflow has deflected east behind the bar. This has coincided with river mouth bulge being 'planed-off', the clockwise pivoting of the Neils Beach shoreline, the accumulation of a drumstick-shaped sediment deposit on east side of river mouth, and eastward retreat of the right bank of river (compare 2003 and 2013 images in Figure 3-11). Essentially, in this river mouth state the river only feeds sediment to the shore north-east of the river mouth (where some of it becomes trapped on the 'drumstick'), while the removal of the bulge and shore pivoting enables waves arriving from the west to sweep sediment eastward off Neils Beach.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2013 Vegetation Line
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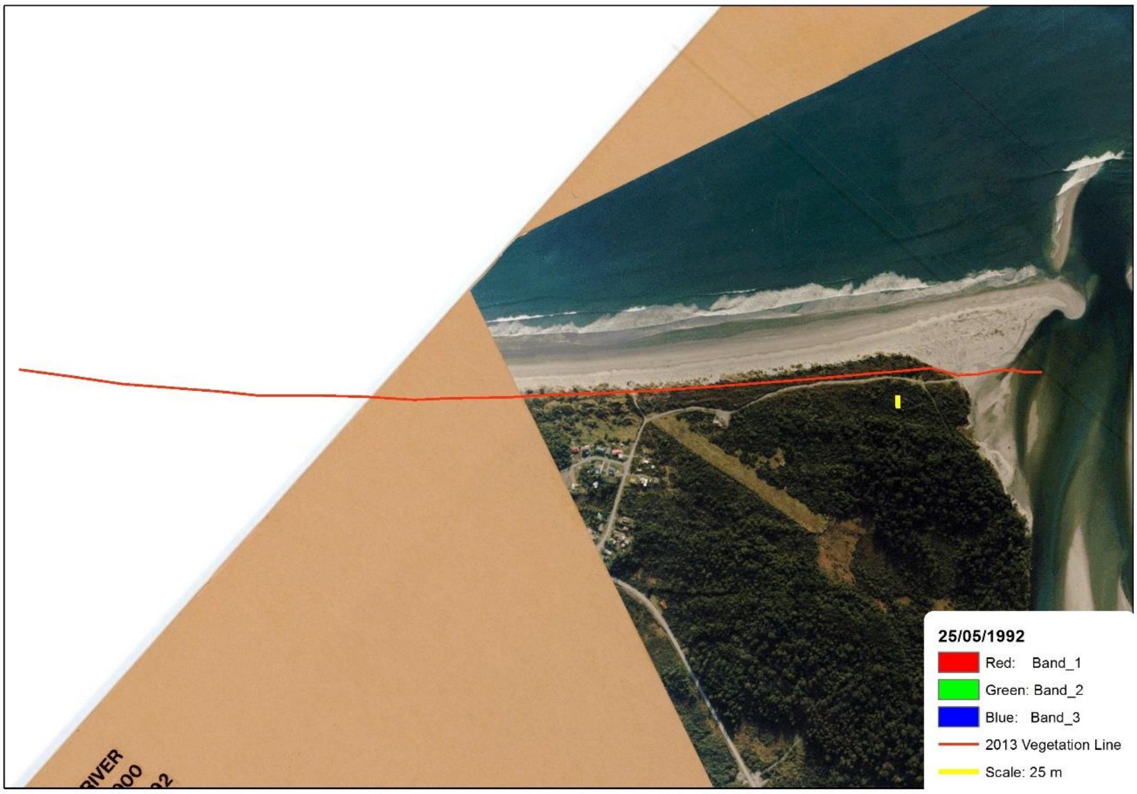
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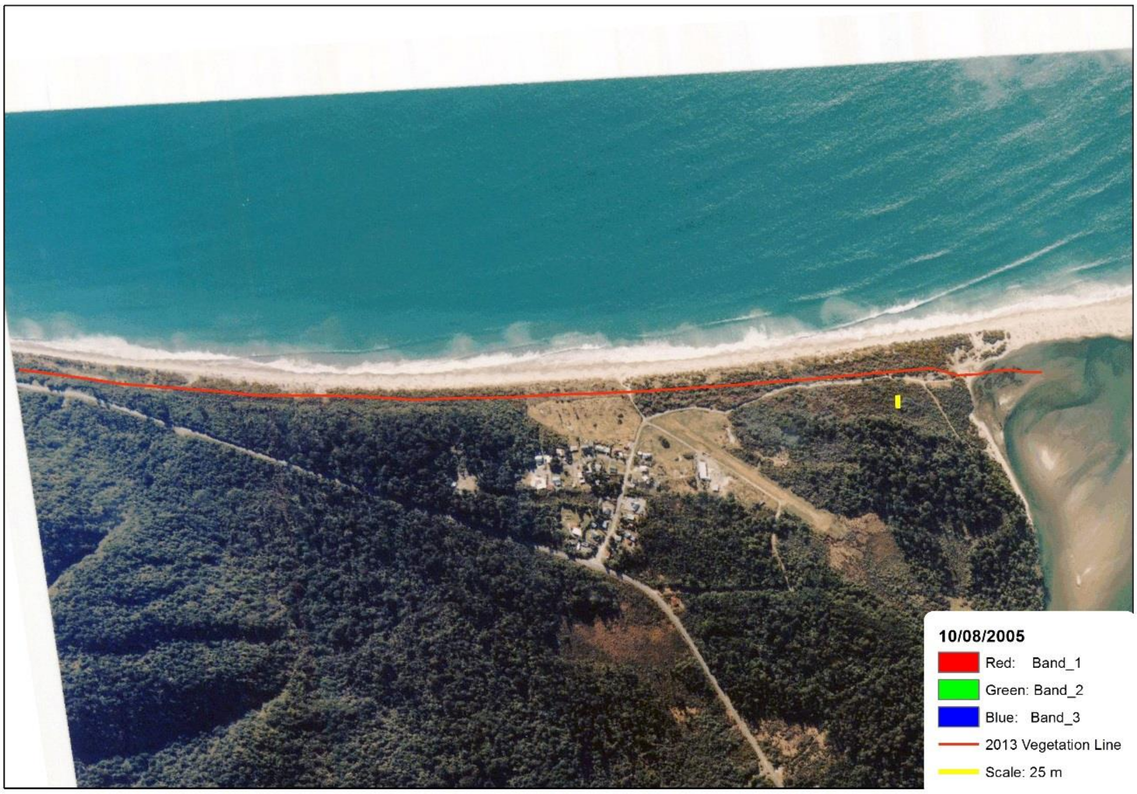

10/08/2005
Red: Band_1
Green: Band_2
Blue: Band_3
2013 Vegetation Line
Scale: 25 m


©2010 Google
06/12/2010
Red: Band_1
Green: Band_2
Blue: Band_3
2013 Vegetation Line
Scale: 25 m

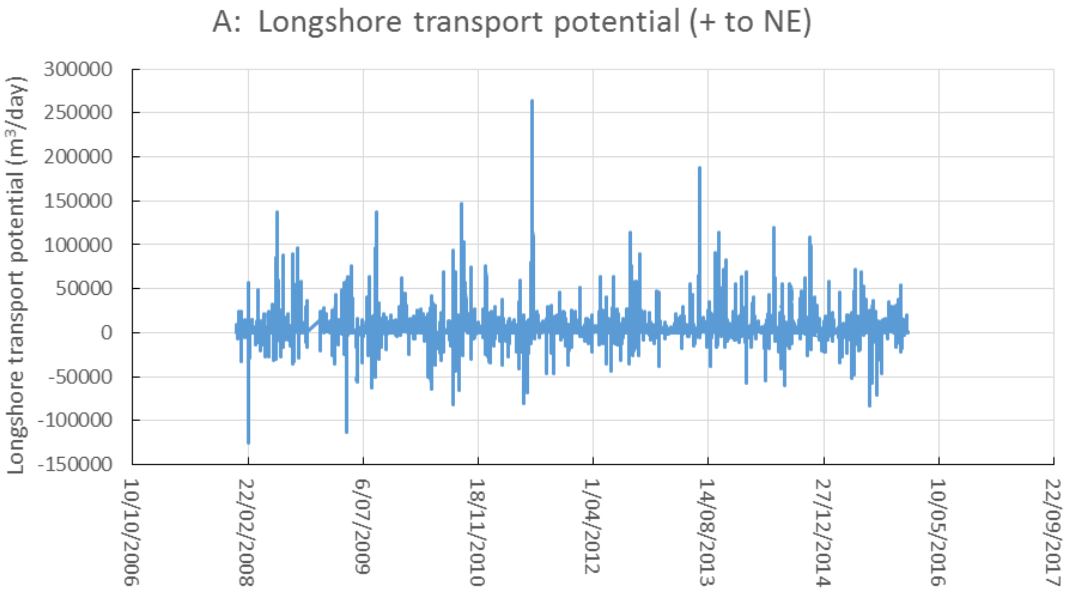
Figure 3-9: Satellite/aerial imagery sequence of Neils Beach, 1977 through 2013. 2013 vegetation-edge shoreline (red line) overlaid on each image.

Figure 3-10: Satellite image of Neils Beach acquired on 9 April 2013, with previous shorelines overlaid. Shorelines defined by the edge of vegetation. 'O' marks linear feature inferred to be old shoreline (possibly ~ 1977?); 'E' shows foredune scrub now lost to erosion. Where there is a date range (e.g. 2003-05) the shoreline changed little between two images and so only one line is plotted.

Figure 3-11: Neils Beach and Arawhata River mouth in 2003 and 2013. Note on 2013 image: flattened delta 'bulge', northward-displaced mouth, 'drumstick' growth on east side of river mouth, and right bank of river trimmed back.

3.4.2 Waves and longshore transport potential

Since January 2008, NIWA has forecast 'deep-water' wave conditions (height, period, direction) around the New Zealand coast based on wind fields predicted by a global-scale atmospheric circulation model. Archived data from this forecasting for a station 15 km seaward of Jackson Bay was supplied by Dr Richard Gorman (NIWA, Hamilton). This record was converted into an approximate record of wave-driven longshore transport potential at the shore using the formula provided by Ashton and Murray (2006), assuming a straight shore with a regional orientation of 237 degrees (i.e., approximately SW-NE) and adopting an "efficiency factor" appropriate for a beach of gravelly sand[2]. The longshore transport potential is shown in Figure 3-12A, and the accumulated transport is shown in Figure 3-13.



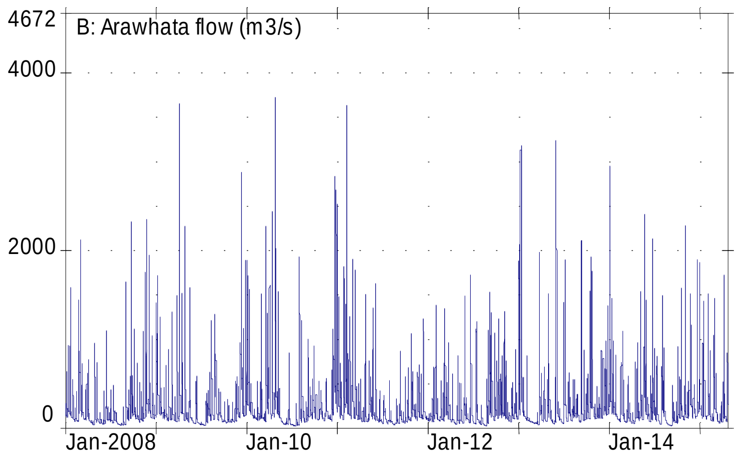


Figure 3-12: A: Longshore transport potential past Arawhata River mouth, 2008-2015; B: Flow in Arawhata River, 2008-2015.

[2] Refracting and shoaling the wave data from the deep-water station into Jackson Bay was beyond the scope of this study so the actual transport rates derived using the simplifying, straight-shore approximation should be regarded "with a grain of sand". Nonetheless, these should still provide an index of temporal patterns in the strength of the longshore transport potential.

North-eastward longshore transport dominates (80% of the gross transport is to the north-east), with a net north-east transport averaging ~ 1.6 million m^3/yr. This is reflected in the accumulating plot (Figure 3-13) which shows a steady 'climb' albeit with occasional small drops. Sudden 'jumps' in this plot indicate high wave events with large transport potential – the largest occurred in July 2011, when the deep-water significant wave height rose to 8.3 m for waves arriving from the west and the north-eastward longshore transport potential rose to ~270,000 m^3/day.

3.4.3 Arawhata River flows and sediment load

The Arawhata River flow record for the period coinciding with the wave record (2008-2015) is plotted in Figure 3-12B. This shows floods peaking at up to 3700 m^3/s but also an almost two-year period in 2011-12 lacking any large floods.

This flow record was combined with a regional suspended sediment rating (unpublished, developed by the author) to generate a record of beach-grade sediment yield from the Arawhata River. The rating is C (mg/l) = 39 $(Q/Q_{mean})^2$, where C is the suspended sediment concentration, Q is flow, and Q_{mean} is mean flow (214 m^3/s for the Arawhata). This was derived using sediment gauging data from the Haast, Hokitika, Whataroa, Poerua and Taipo Rivers. Suspended sediment size-grading data from the Haast River showed that, on average, 31% was fine sand and coarser (i.e. the size grades found in beach sediment), thus it was assumed the same would apply to the Arawhata. Also, it was assumed that the Arawhata's sandy gravel bedload should equate to ~ 20% of its suspended load (based on experience with other rivers). Thus, it was estimated that the Arawhata's load of beach-grade sediment should equate to 51% of its suspended load.

Figure 3-13 also shows the accumulated delivery of Arawhata beach-grade sediment from 2008 through 2015. The average delivery is 1.07 million m^3/yr (assuming a bulk density of 1.7 t/m^3). Note how floods cause jumps in the accumulated sediment delivery while flat parts of the curve indicate periods of minimal delivery. 2011-2012 was such a period.

Figure 3-14 plots the annual beach-grade sediment delivery since 1989, when flow recording began in the Arawhata. This shows considerable variability from year to year (0.38 to 2.93 million m^3, ranging over a factor of 7.7). The two highest annual yields (2.2 and 2.9 million m^3) occurred in 1994 and 1999 associated with the two largest floods on record (4770 m^3/s on 9 January 1994 and 4260 m^3/s on 17 November 1999). It is notable that these events immediately precede the 1995-2005 accretion phase along Neils Beach that was identified in Section 3.4.1. Note also a long span of relatively 'modest' annual loads from 2000 through 2008.

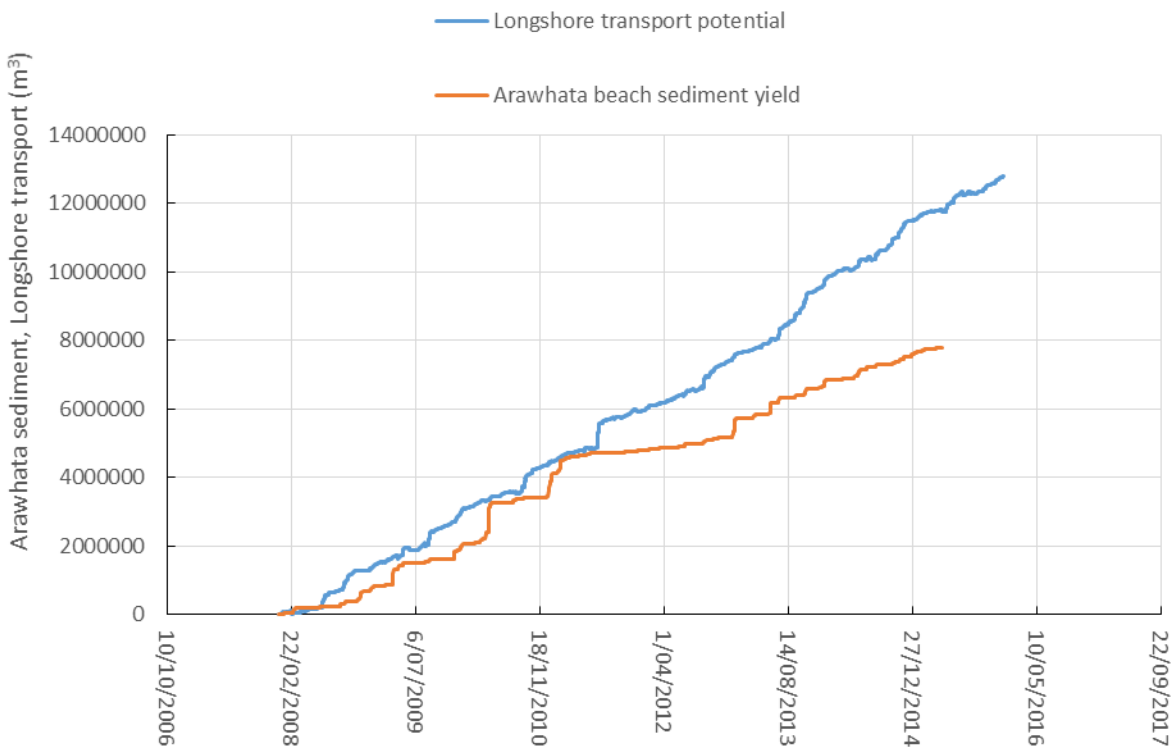


Figure 3-13: Longshore transport potential at Arawhata mouth and delivery of beach-grade sediment from Arawhata River accumulated since January 2008. Note divergence of the two trends after 2011.

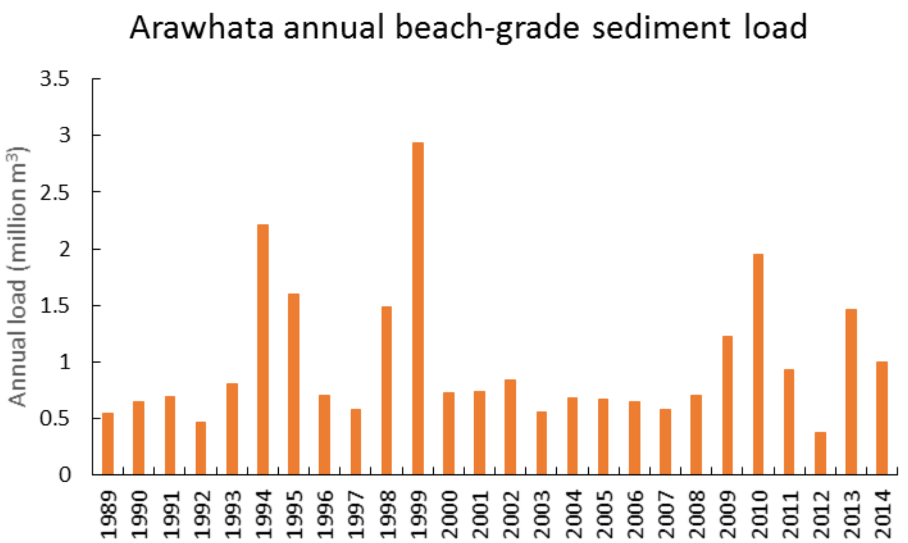


Figure 3-14: Annual load of beach-grade sediment delivered by Arawhata River, 1989-2014.

3.5 Synthesis and interpreted cause of erosion

In overview, Neils Beach fronts the western side of the Arawhata River delta, which has a form determined by the interplay of coastal and river processes. When the delta 'bulges' seaward, following Arawhata floods bearing sand and gravel, the shoreline configuration is such that beach-grade river sediment is spread west by waves arriving from the NW quarter, stocking up Neils Beach, while the bulge also acts as a 'soft groyne', hindering the eastward transfer of sediment off Neils Beach when waves arrive from the prevailing westerly quarter. At other times though, coinciding with periods of relative dominance by coastal processes, the river mouth bulge is 'planed-off' and the river outlet is forced eastward. This situation causes Neils Beach to erode; firstly because the 'soft groyne' is trimmed-off, allowing the prevailing westerly waves to sweep sand off Neils Beach; secondly because the diverted river no longer deposits its sandy gravel load where waves can sweep some of it westward onto Neils Beach. Such accretion and erosion cycles are typical of wave-dominated river mouth shores, and they explain the cycles observed on the imagery of Neils Beach over the past 40 years.

In regard to the current phase of erosion, Figure 3-13 shows a clear divergence between the longshore transport potential and the Arawhata's delivery of beach-grade sediment from 2011 onwards[3] - thus indicating an imbalance in the beach sediment budget. Moreover, the strong coastal wave event of July 2011 was followed by almost two years of relatively benign river flows with low sediment delivery. The dominance of wave-driven processes over this period can be expected to have pushed- and trimmed-back the shoreline at the river mouth and also extended-eastward the river mouth bar (as observed on the aerial and satellite imagery). In turn, this would have directed what river sediment was being delivered to the east side of the river mouth (and remote from Neils Beach), while the straightened, river-mouth shore would have allowed waves to transport sediment eastward off Neils Beach.

Thus, I conclude that the recent erosion phase was likely triggered by a combination of natural factors (a very large wave and longshore transport event followed by two years of benign river flows and low sediment delivery), creating a mouth configuration that allowed Neils Beach sediment to "leak" northward past the river mouth and not allowing it to be restocked by the river.

The field visit in October 2015 found evidence that the Arawhata River has now returned to its more normal position closer to Neils Beach, with some renourishment occurring from river sand and gravel and less sediment "leaking" eastward. However, it will likely require some years or even decades for the beach sediment stocks rebuild again – particularly towards the western end of Neils Beach – as the accretion will progress from east to west. In the meantime, the shore remains vulnerable to further erosion from storm waves.

In the long-term, the Neils Beach shore will always remain vulnerable to erosion/accretion cycles driven by river/coastal interactions.

[3] The two curves in Figure 3-13 may be likened to the "run" curve shown in limited-over cricket match TV commentaries. Diverging curves show where one team is falling behind the target set by the other. In this case, the 'Arawhata River team' began losing to the 'Longshore transport team' in 2011.

3.6 Management options

Various management options have been suggested for Neils Beach. These are discussed briefly below in the context of the above understanding of the cause of the current erosion phase.

- **Do nothing**: Doing nothing means being optimistic that the beach has now moved into an accretionary phase, gradually naturally restocking itself with river sand. A difficulty with this is that the erosion will continue along the western and central parts of the beach even while the beach is building out from its eastern end. Thus, the current elevated hazard situation will prevail for some years yet.

- **Groyne**: A groyne at the east end of Neils Beach designed to limit eastward sediment transport would have mixed effects – while it might slow the sediment loss off Neils Beach it would also limit its occasional renourishment with river sediment. Moreover, if a groyne was built with Neils Beach in its currently depleted state, it would need to be restocked artificially (i.e., it would also require beach nourishment).

- **Sea wall**: Protecting the eroding shore with a structure would be expensive, would not rectify the current beach sediment deficit, and would run the risk of exacerbating the erosion. Construction of a sea wall is, therefore, unlikely to be an effective long term solution.

- **Gravel bund**: A bund formed of beach/river gravel would provide an expedient time-buying measure to afford some shore protection while/if the beach naturally restocks with sediment (assuming it is now moving into an accreting cycle). This would be much better built of imported material (e.g. sourced from the Arawhata bed) than scraped-up from the existing beach.

- **Beach nourishment**: Beach renourishment (with imported material, again most likely sourced from the river) would accelerate returning the shoreline to a safer condition.

- **Mechanical repositioning of Arawhata River Mouth**: The recent rapid erosion is likely linked to the river mouth moving to a more easterly position. The Arawhata River has now returned to a more westerly position but if the river mouth were to move east again it may well be beneficial to make an artificial cut.

- **Avoidance/setback**: In the long term it is likely that this stretch of shoreline will continue to be at risk of erosion due to the multi-decadal erosion/accretion cycles discussed above. Moreover, rising sea-levels associated with future global climate change will render the shore more vulnerable to retreat. Thus, an avoidance/setback option would be most sensible in the long term.

3.7 Recommendations

My recommendation for Neils Beach would be to combine several of the above options in a staged/as-needed approach:

- Importing sandy gravel from the Arawhata River channel to build a protective bund (and at the same time building up beach stocks)
- Monitoring the position of the shoreline fronting Neils beach and the configuration of the Arawhata River outlet, and, if the outlet migrates east, cutting a new western outlet.
- Develop long-term plans for relocating assets beyond the zone at risk from the erosion/accretion cycles, allowing also for the effects of future sea-level rise and possible changes in wave climate.

4 Conclusions

4.1 Hokitika River mouth

The Hokitika River mouth bar is unlikely to significantly affect flood levels in the estuary because the river path to the south side of the river mouth is not substantially longer compared to the direct outlet path, while a large flood could be expected to quickly enlarge the outlet channel. The present mouth configuration is, if anything, facilitating the northward wave-driven transfer of sand and gravel from the river mouth area to the Hokitika foreshore. The eroding span of shore on the north side of the Sunset Point carpark is eroding primarily because it is indented back from the line of the two robust seawalls, which causes end-effects.

The recommendations are to:

- do nothing about the river mouth bar immediately, but monitor its form and if it grows substantially from its present state consider an artificial cut past Sunset Point
- link the robust seawalls at Sunset Point and fronting Hokitika town centre together into a continuous wall along a smooth line, with the linking section built to the same standard as the two existing end segments.

4.2 Neils Beach

Neils Beach lies on the western flank of the wave-dominated Arawhata River delta. It is nourished largely by Arawhata River sediment but also by sediment from local hillslope sources along the rocky shore towards Jackson Bay. It experiences decadal-scale erosion/accretion cycles relating to the interplay of coastal waves and the delivery of sand and gravel from the river during floods: accreting after large river floods that deliver sediment to the western end of its delta, but eroding when the river is deflected eastward and waves trim off the apex of the delta - which enables Neils Beach sediment to be swept eastward and lost. The present erosion phase appears to be linked to an extended period in 2011-12 of benign river flows but strong eastward, wave-driven longshore transport that forced the river to deflect east. While the river outlet has now shifted west again and the eastern end of Neils Beach appears to be beginning a recovery phase, it may require years to decades to naturally re-stock and advance the shoreline along the rest of Neils Beach, including in front of the settlement and airstrip.

To mitigate the existing erosion and sea-flooding hazard, a combination approach is recommended:

- import gravel from the Arawhata River channel to build a protective bund (and at the same time building up beach stocks)
- monitor the position of the Arawhata River outlet, and, if the outlet migrates east, cut a new western outlet
- develop long-term plans for relocating assets beyond the zone at risk from the erosion/accretion cycles, allowing for the effects of future sea-level rise and possible changes in wave climate.

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