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11TH IAG INTERNATIONAL CONFERENCE ON GEOMORPHOLOGY

# FIELDTRIP GUIDE

## COASTAL GEOMORPHOLOGY OF THE NORTHERN CANTERBURY COASTLINE

2026

IAG GEOMORPHOLOGY · ANZGG Australian & New Zealand Geomorphology Group · manatiaki kōawa rivers GROUP A joint technical interest group of Engineering New Zealand & Water NZ

# 11TH IAG INTERNATIONAL CONFERENCE ON GEOMORPHOLOGY

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Cover Photos: Wairongomai-Mangarara (Credit: Ian Fuller), Aoraki Mt. Cook National Park (Credit: Sam McColl), and Waikato at Taupo (Credit: Sarah McSweeney).

# Coastal Geomorphology of the Northern Canterbury Coastline

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## Field guide for the International Conference on Geomorphology mid-conference field trip

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Supported by: Laura Somerville (Environment Canterbury and Kate Macdonald (Jacobs Consulting).

Image: Gore Bay Beach looking towards the north. Photo credit: S. McSweeney.

## 1.0 Introduction

Welcome to our International Conference on Geomorphology (ICG) mid-conference field trip! This one-day field trip travels north along State Highway 1, from Christchurch to Gore Bay, and then returns south through the Hurunui district back to Te Pae (Figure 1; Table 1). Travel is by coach. Please note that driving time is ~1.5 hours to the first restroom stop at Cheviot.

We will visit a diverse range of coastal landforms including estuaries, hapua (braided river mouth lagoons), eroding cliffs, and mixed-sand and gravel and sandy beaches. Each stop will offer spectacular lookouts of the coast and as we drive through the hinterland, you will also see active hillslope processes and evidence of tectonics. The trip will cross several major river systems and will meet them again downstream at the coast and visit their estuaries and lagoons. Both coastal and inland erosion is prominent in the area and we will visit communities facing severe coastal erosion. Coastal managers, scientists, and community members will share their knowledge at some locations in addition to field trip leaders. The Hurunui region (just north of Christchurch) is well known for its outstanding vineyards. We will visit the Terrace Edge Vineyard (which overlooks the Waipara River terraces) for a picnic lunch, with optional wine tasting and purchasing available, on our way back to the city.

## 1.1 Itinerary and travel route

Figure 1 below shows our travel route and stops along the way. Table 1 (on the next page) provides an itinerary and indicative timings for the trip.

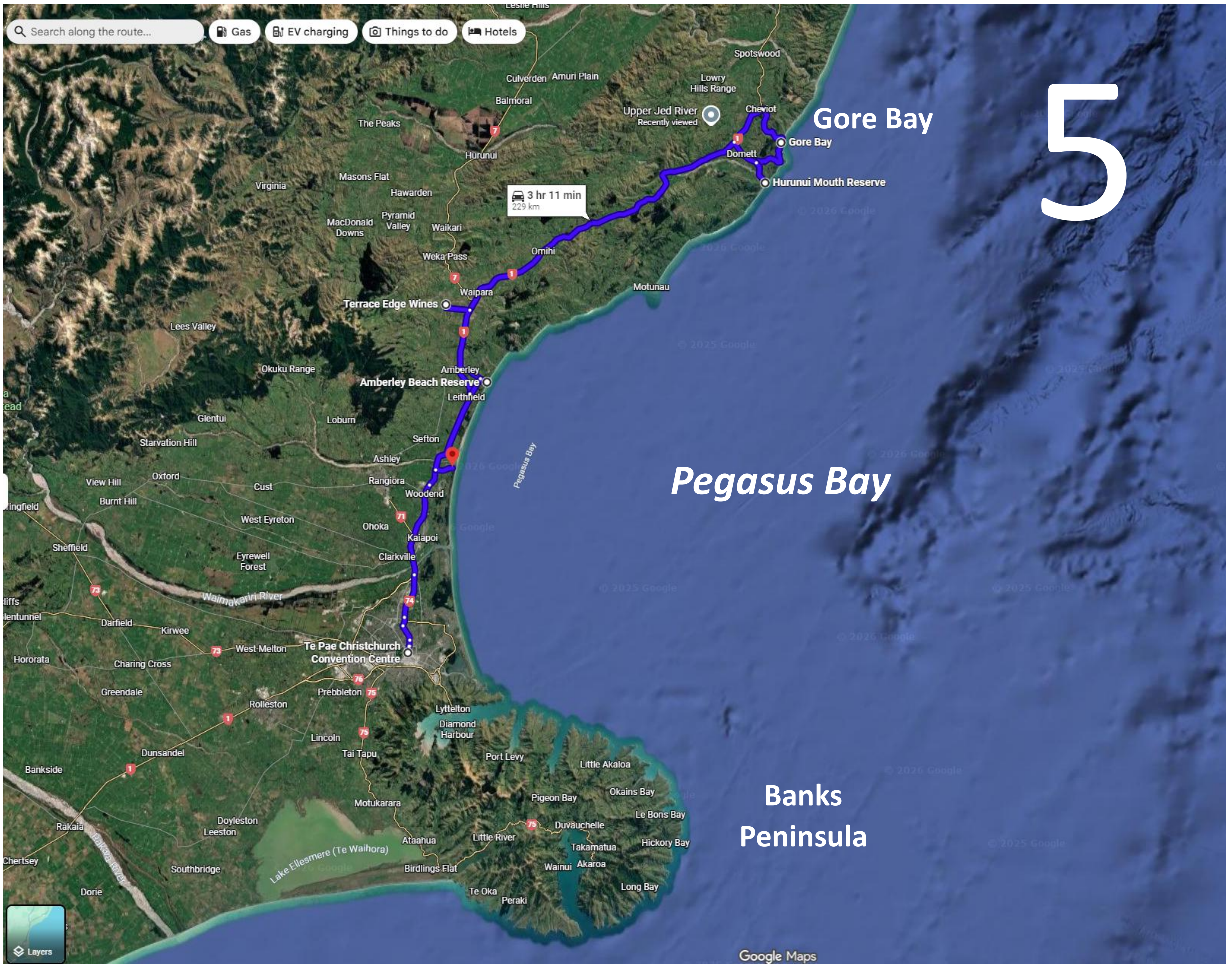


**Figure 1.** Map of travel route and stops. To be read in conjunction with Table 1 (next page).

**Table 1.** Itinerary and approximate timings of stops.

| Stop | Arrive | Depart | Notes |
|---|---|---|---|
| Pick up:<br>Te Pae, Christchurch | | 0740 | **Please note there will be approximately a 1.5 hour drive until the next restroom stop.** |
| Cheviot restrooms, Cheviot<br>(-42.8111°, 173.2741°) | 0915 | 0930 | Quick restroom stop. |
| Stop 1: North Gore Bay at Buxton Reserve<br>(-42.8547°, 173.3115°) | 0940 | 1020 | • Introduction to the region and scene setting<br>• Mixed-sand and gravel beach processes<br>• History of the Jed-Buxton river mouths and current erosion threats. Guest speaker: Laura Somerville (Environment Canterbury)<br>• Option to walk further up the beach and to view the estuaries and barrier (~15 mins round trip)<br>• **Toilet available.** |
| Stop 2: South Gore Bay at Old School Reserve<br>(-42.8642°, 173.3079°) | 1030 | 1115 | • Lithology, eroding cliffs, and shore platforms.<br>• Spatial trends and drivers of cliff and beach erosion.<br>• Option to explore the beach<br>• **Morning tea at reserve rest area**<br>• **Toilet available.** |
| Stop 3: Cathedral Gully<br>(-42.8679°, 173.3043°) | 1120 | 1135 | Look at erosional features/Cathedral Cliffs. A view across the bay. Wrap up talk about the Gore Bay coastal cell. |
| Stop 4: Hurunui River hapua<br>(-42.9067°, 173.2881°) | 1150 | 12.30 | • Discussion about hapua, river mouth and barrier dynamics, and different pressures on the system.<br>• Guest speaker: Prof. Deirdre Hart (University of Canterbury) |
| Stop 5: Terrace Edge Vineyard, 328 Georges Road, Waipara<br>(-43.07155°, 172.7046°) | 1315 | 1415 | • **Lunch stop.** Packed picnic lunch outside overlooking the Hurunui River terraces and a chance for wine tasting and/or purchasing for those who would like.<br>• **Toilet available** |
| Stop 6: Amberley Beach<br>(-43.1753°, 172.7787°) | 1445 | 1535 | • Discuss Pegasus Bay coastal geomorphology<br>• Erosion and management issues at Amberley Beach.<br>• Guest speaker: Kate MacDonald (Jacobs Consulting)<br>• Student research/issues around Waipara river mouth and links to beach erosion<br>• **Toilet available.** |
| Stop 7: Rakahuri Ashley River mouth and Waikuku Beach<br>(-43.2834°, 172.7201°) | 1355 | 1630 | **N.B. We will only stop if time permits on the day**<br>• Estuary processes<br>• Coastal sand dunes, land use change, ecology<br>• Pegasus Bay grain size change on the beach. |
| Drop off:<br>Te Pae, Christchurch | 1700 latest | | |

## 1.2 What to bring

- Water (1-2 L minimum) and any additional snacks
- Sun protection (sunhat, sunscreen, sunglasses)
- Warm layer(s) and windproof/waterproof jacket
- Sturdy walking shoes (some sand and shingle beaches)
- Any personal medication.

**Lunch and morning and afternoon tea will be provided. Water will be available throughout the day and taken with us on the bus, but please plan to bring enough in your own water bottle so you do not go thirsty.**

## 1.3 What to expect

Some stops will include short walks between the vehicle and viewpoints. No walk on this trip will be longer than ~400 m. Most walking is on stable ground, but there will be one mixed-sand and gravel beach (Gore Bay) which can be quite steep. It is optional to walk on and explore this beach. If you prefer not to, there is a covered shelter for people to relax at and enjoy a nice view towards the sea.

Lunch and morning + afternoon tea is provided. Lunch will be a packed picnic lunch which we will eat outdoors at Terrace Edge Winery. There will be a chance for you to sample or purchase local organic wines, or just simply sit outside and enjoy the view across the impressive Waipara River terraces. If the weather is poor, we will have lunch in a sheltered location.

## 1.4 Safety briefing: key hazards

- Unpredictable waves and strong backwash – especially on steep shingle beaches. Stay well back from the swash zone and do not turn your back to the ocean.
- Rockfall and small landslides below cliffs and gully walls (especially after rain). Do not linger at cliff toes.
- Slippery shore platforms and algae-covered rock. Treat all intertidal rock as potentially slick. South Gore Bay is the only area where this is a prominent hazard.
- Traffic hazards. We will not be stopping directly on the road for any stops, but please be aware of any traffic in carparks or if you venture near or across roads.
- Sun exposure and dehydration. UV can be extreme even on cool or cloudy days in Aotearoa New Zealand, especially this time of year.
- The weather in Aotearoa New Zealand can often be very changeable. Pack clothes for warm/windy/wet conditions in your field backpack for the day.

Field leaders will call the day's risk level and confirm any no-go areas based on swell/tide, recent rainfall, and visible cliff instability. Participants are asked to be aware of conditions at all times, especially when near cliff edges or on the active beach face, and keep an eye out for each other.

## 1.5 Tide times and heights

At Gore Bay, for Wednesday 4th February 2025, the tides are:

- High tide is at 7.14 am (1.82 m)
- Low tide is at 1.35 pm (0.09 m).

## 2.0 Regional setting

### Geology

Northern Canterbury lies within the broad deformation zone of the Australia–Pacific plate boundary (Figure 2). Although the Alpine Fault accommodates much of the relative plate motion further west, significant strain is distributed across the eastern South Island via active faults and folds. For coastal geomorphology, the key consequences are (i) long-term rock uplift and tilting, (ii) a landscape with high relief and active hillslope processes supplying sediment to rivers, and (iii) preservation of emergent marine landforms such as raised shore platforms and marine terraces. During the Last Glacial Maximum (LGM) sea level was ~125 m lower than present in the Canterbury region. Relative sea level s generally interpreted to have reached approximately present mean sea level, or slightly above it (up to ~+1 m) between ~7 and 5 ka during the mid-Holocene highstand. In the late Holocene (last ~5-4 ka), sea level has been stable to slowly falling (Clement et al., 2016).

### The tectonic setting of the Hurunui District

Tectonic uplift in the Hurunui District enhances sediment supply from the hinterland, with rivers such as the Hurunui delivering large volumes of coarse greywacke-derived material to the coast. This sediment supply, combined with ongoing uplift, supports predominantly mixed sand and gravel beaches, narrow coastal plains, and dynamic river-mouth systems. Differential uplift and fault-controlled topography influence coastal orientation and nearshore bathymetry, affecting wave transformation and alongshore sediment transport. Consequently, coastal geomorphology in the Hurunui District reflects strong tectonic control interacting with energetic marine and fluvial processes. The 2016 Mw 7.8 Kaikōura earthquake (north of today's route) provides an important regional reference point for understanding how coseismic uplift/subsidence can re-set coastal morphology over minutes to hours, and how those signals may be preserved (or erased) in the longer-term terrace record.

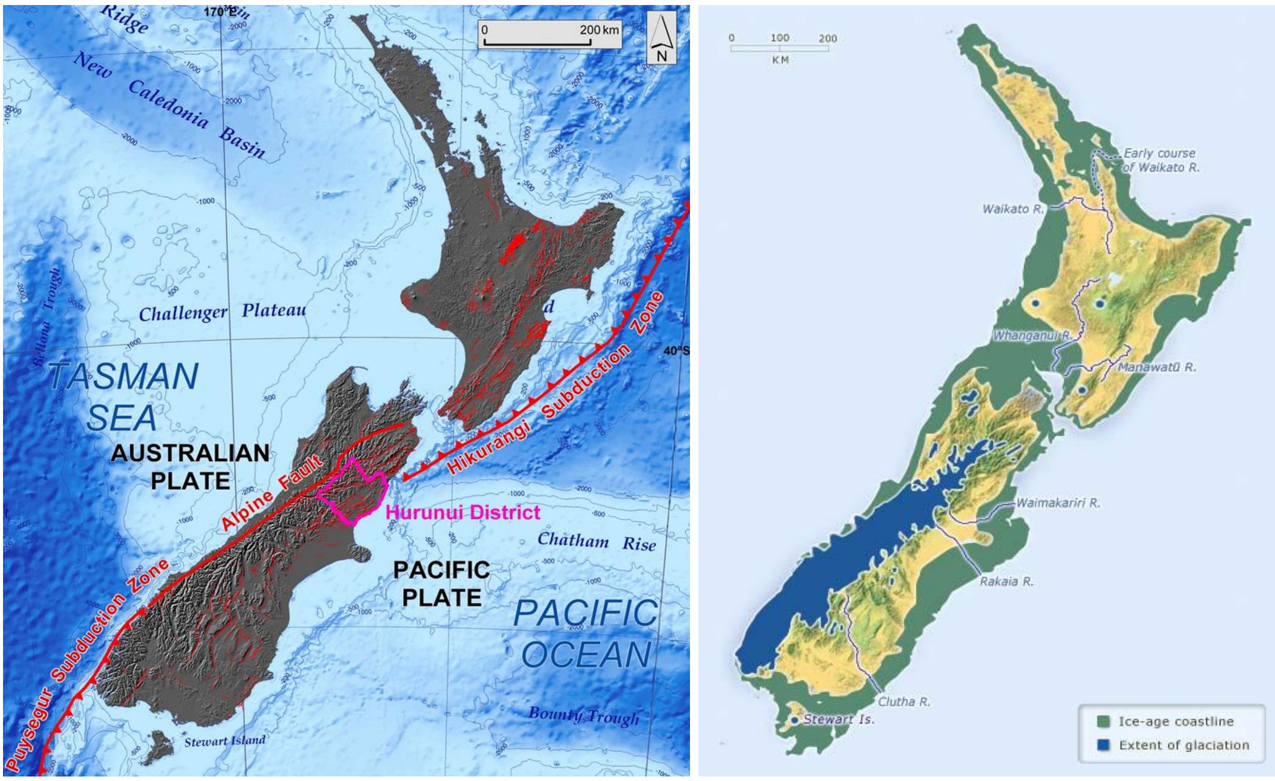


**Figure 2.** (Left) Tectonic setting of New Zealand (Barrell and Townsend, 2012) and (right) LGM shoreline which was ~125 m lower than today, exposing the continental shelf (Te Awa, 2025).

## Marine setting:

The east coast of the South Island is exposed to long-fetch swell from the Southern Ocean and South Pacific (Figure 3). Wave approach is commonly from the south to southeast in storm conditions. Refraction around Banks Peninsula produces alongshore gradients in wave energy within Pegasus Bay (just north of Banks Peninsula) (Figure 4). These gradients interact with headlands and nearshore bathymetry to define coastal cells with contrasting erosion and accretion behaviour over kilometre scales. In Pegasus Bay, the currents and circulation cells vary and recirculation reverses currents (Figure 4.) Some storms come from the northeast. Tides are microtidal on the open coast.

Northern Canterbury beaches commonly comprise mixed sand and gravel (MSG) or composite beach states. Sediment supply is strongly source-to-sink connected: coarse sediment is generally delivered by braided rivers draining the Southern Alps (e.g., Hurunui, Waimakariri), while local cliff erosion contributes finer sand and silt as well as gravel where conglomerates are exposed. Longshore transport is typically northward during high-energy southerly events, but short-term reversals can occur with changing wave approach. Within this framework, estuaries, hāpua, and embayed beach systems become sensitive indicators of shifts in sediment supply and event sequencing.

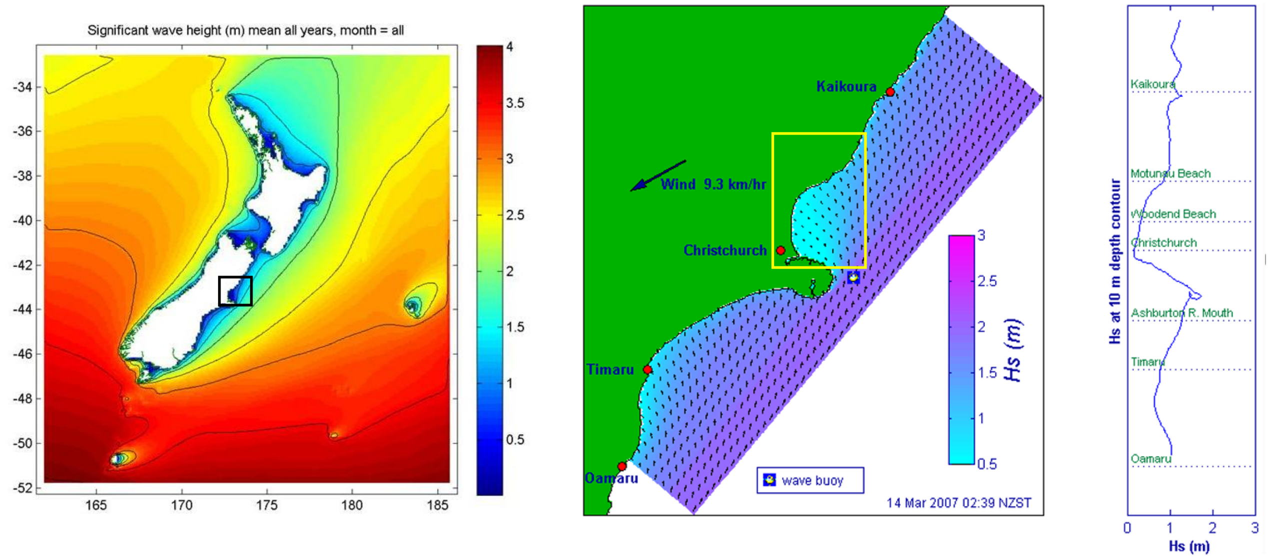


**Figure 3.** (Left) Mean significant wave height for New Zealand with the northern Canterbury area visited on this tip outlined by the black box. (Right) Wave height and direction along the Canterbury coast. Vectors are wave direction. Refraction and sheltering just north of Banks Peninsula is clear (adjacent to Christchurch in Pegasus Bay). NIWA (2025).

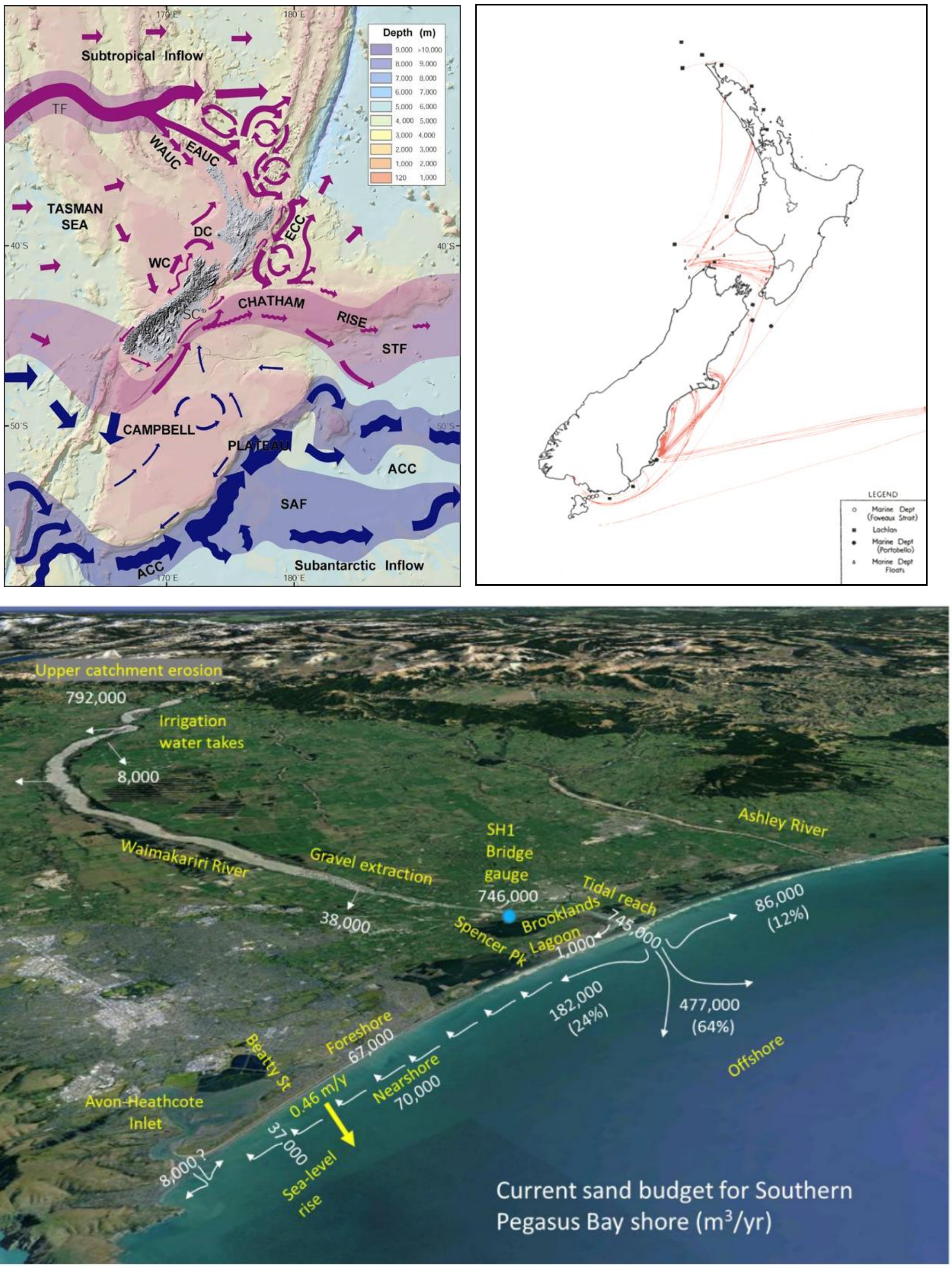


**Figure 4.** (Top left) Ocean currents of NZ (Te Awa, 2024). For Canterbury. the Southland Current (SC) tracks northward along the east coast of the South Island. (Top right) racks of drift bottles and floats released in New Zealand coastal waters 191B1952. Approximate shortest tracks between release and recovery are shown. Note the recirculation eddy around banks peninsular (middle of the east coast of the South Island) (Brodie, 1960). (Bottom) Pegasus Bay circulation cell showing currents and waves impacted by topography (Hicks et al., 2018). Yellow figures show the space-time-averaged rate of shoreline advance between the Waimakariri River mouth and Sumner.

# 3.0 Field sites of interest

## Stop 1. North Gore Bay

Gore Bay is a 4 km long mixed-sand and gravel (MSG) beach (Figure 5). As the only easily accessible swimming beach between Kaikoura and Amberley Beach, it is a popular holiday spot. Gore Bay is experiencing increasing coastal erosion and inundation – from storm events and the backup of water behind the barrier of the Jed/Buxton Lagoon, and landsliding is occurring on the hills on which some of the township is built. The settlement is located on a narrow raised coastal plain of Holocene sand and gravel and is constrained at its landward margin by tall alluvial and loess cliffs of Tertiary sediment which likely mark the shoreline position 6,500 years ago (Jacobs, 2020). It is a dynamic stretch of coast where people are becoming increasingly impacted by hazards.

Some of the key elements we will discuss at this location are:

- Dynamics of MSG beaches
- Coastal erosion and hazards
- The Jed/Buxton Lagoon (physical processes and management issues).

**If you are lucky, you may see a NZ fur seal on the beach (Figure 5). They often come ashore to rest. If you see one, stay 20 m away and don't try to touch it. They are generally not aggressive but can sometimes lunge for you if they feel threatened or stressed. If they have pups, avoid!**

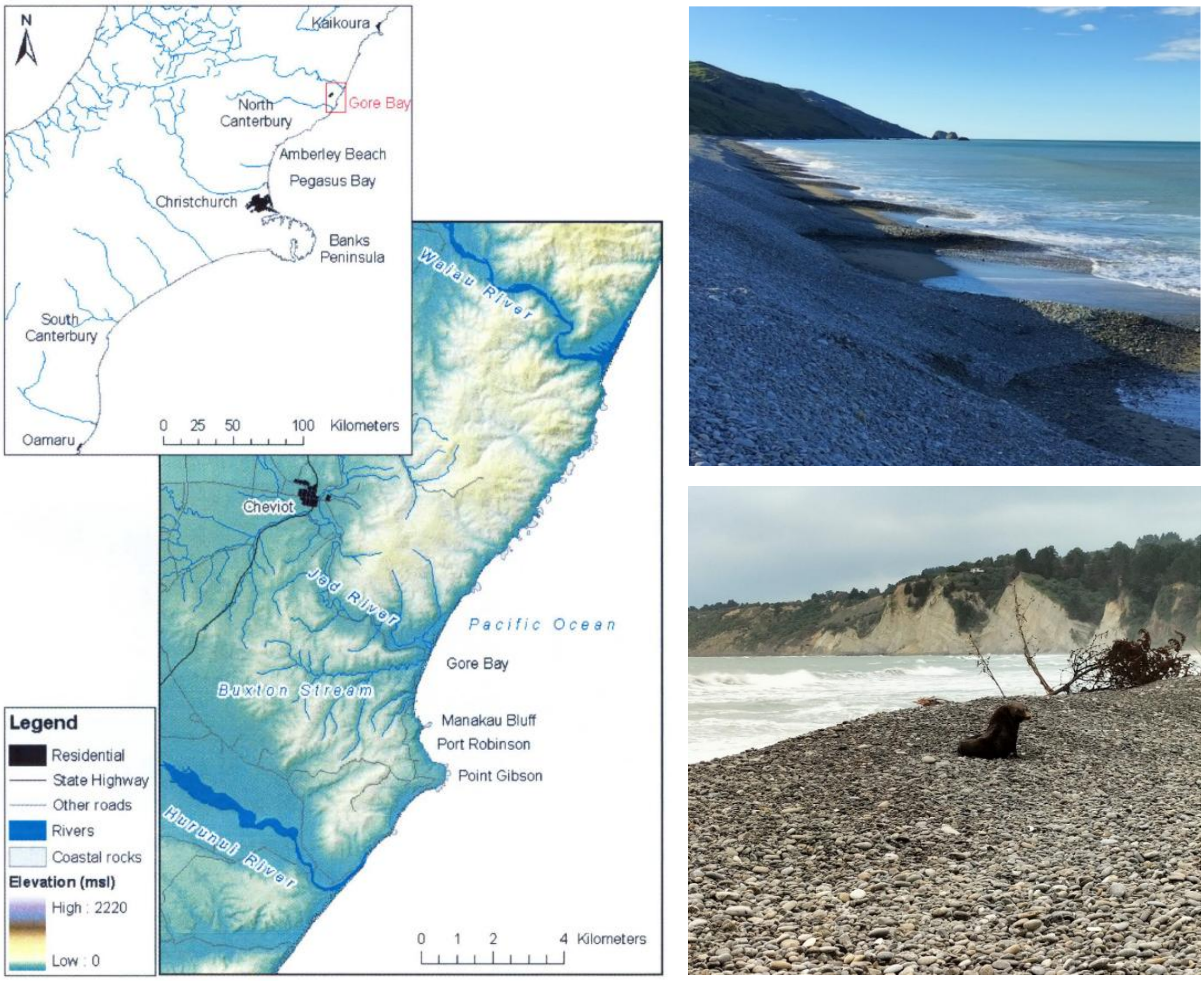


**Figure 5.** Map of Gore Bay (Vessey, 2003) and photos of beach cusps (top) and NZ fur seal (bottom). The top photo is looking towards the north and the bottom is towards the south along Gore Bay.

The geology of Gore Bay is shown in Figure 6 (below). Figure 7 shows a photo looking down on the bay, with landform units identified, and an image of the backshore morphology north of Jed River.

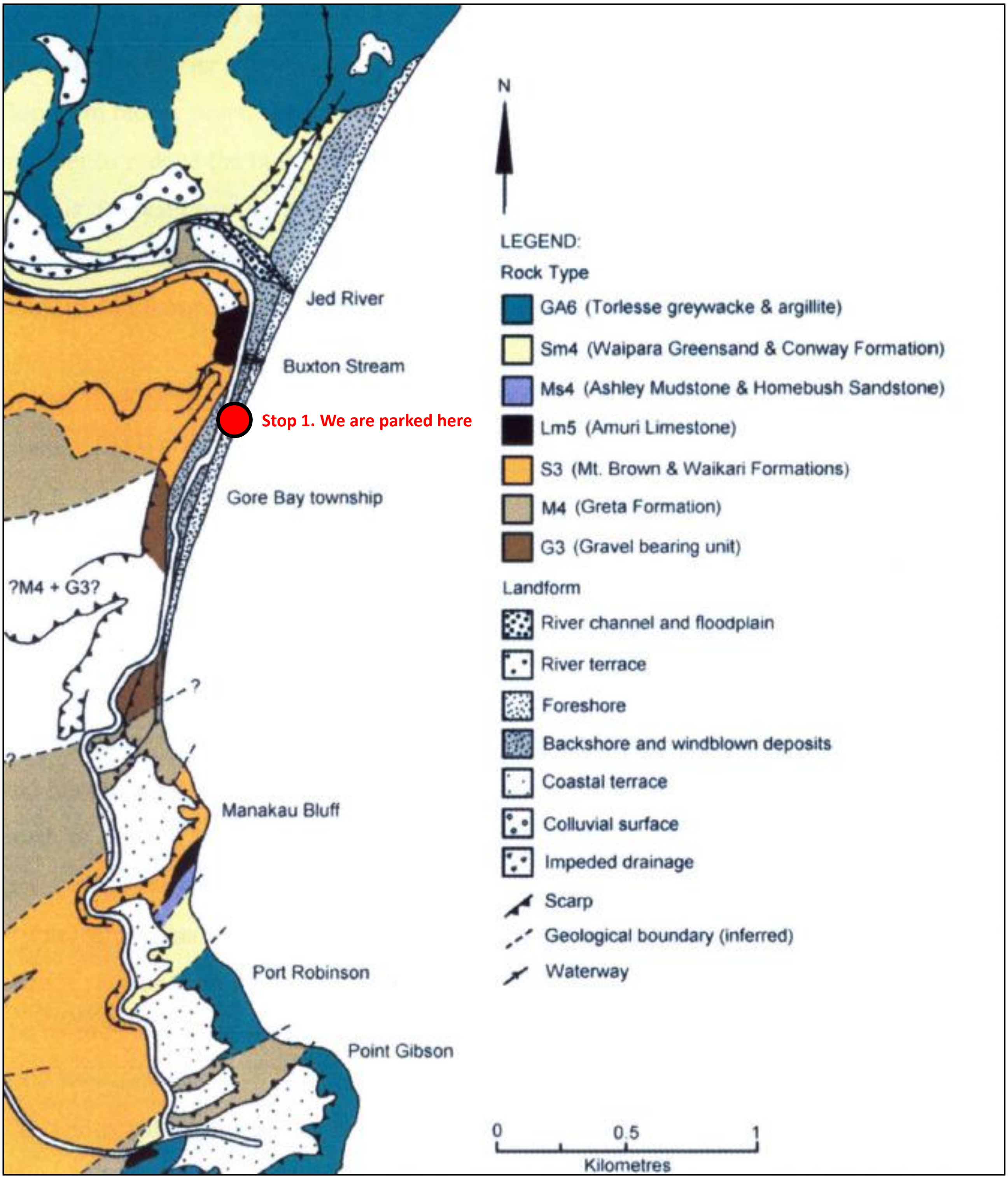


**Figure 6.** The geology and geomorphology of Gore Bay and surrounding areas. Sandstones are represented by the letter S, mudstones by M, gravels by G and limestone by L. The symbol GA refers to the interbedded greywacke and argillite of the Torlesse basement. The number associated with each unit represents the strength or hardness of the unweathered unit, on a scale of one (unconsolidated) to seven (very hard) (after McPherson, 1988; Vessey, 2003).


**Figure 7.** (Left) Looking north along Gore Bay with geomorphic features annotated. Dashed lines border areas of: (A-B) raised terraces and (C) northern coastal plain with relict sand dunes. Arrows point to the (D) Jed River, and (E) Buxton Stream mouths (Vessey, 2003). (Right) Marine terraces and relict sand dunes (location C in previous photo). The beach is to the right hand side of the photo.

## Dynamics of MSG beaches

Gore Bay is generally classified as a MSG beach, where sediment is a mixture of sand and gravel, rather than being dominated by just one size fraction (Figure 8). MSG beaches are common in NZ on high-energy, microtidal wave-dominated coasts where there is a coarse sediment supply – including paraglacial coasts and the leeward margins of Pleistocene fluvio-glacial outwash fans.

MSG beaches in NZ are characterised by:

- **Beach morphology:** Generally steep and narrow beach faces (compared to sandy beaches). Both gravels and sand, with mixing of the two size fractions in the beach deposit. Can show sediment sorting, with gravel concentrated on the upper beach and sand lower on the foreshore. A step in the beach profile at the break point. Storm + swash berms.
- **Hydrodynamics:** Swash-dominated rather than surf-dominated. Gravel increases permeability, allowing rapid infiltration of swash, which promotes steeper slopes.
- **Response to waves and storms:** Respond quickly to storms, with gravel berms forming or being reworked.

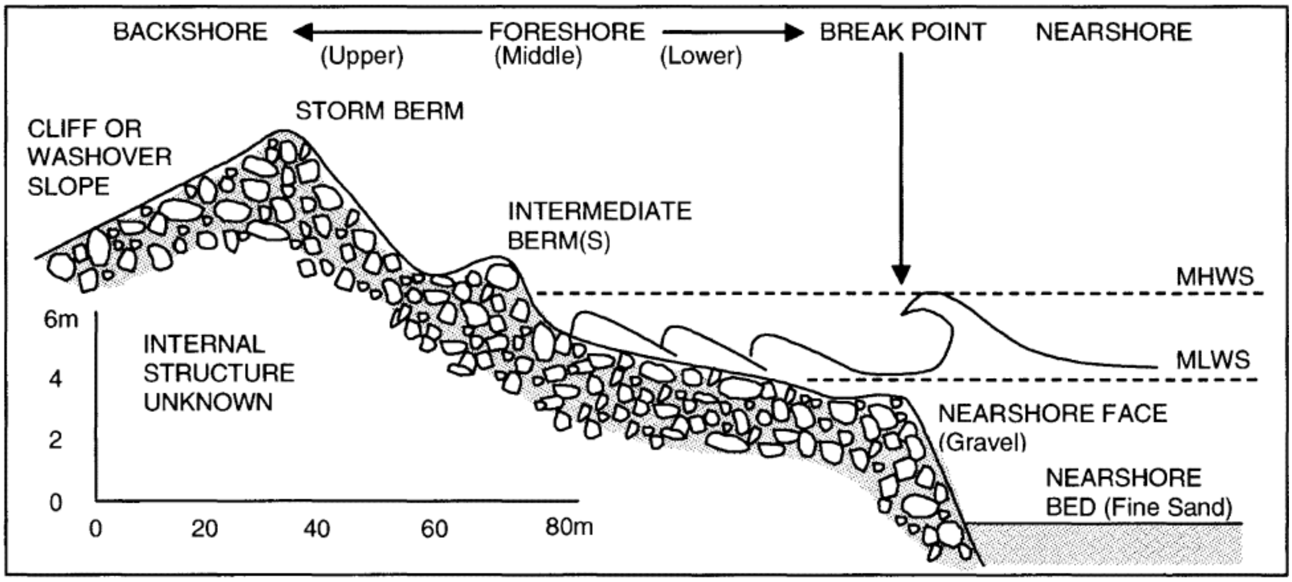


**Figure 8.** A typical mixed sand and gravel profile for NZ beaches (after Kirk 1980; Vessey, 2003).

The beach morphology of Gore Bay varies alongshore and can switch between composite and MSG beach states. This has resulted in Gore Bay being referred to as a "transitional" MSG beach (Vessey, 2003; Jacobs, 2020) (Figure 9). Along Gore Bay, the distribution of sand and gravel varies both spatially and temporally, as does the beach morphology. Coarser sediment is generally concentrated in the north, where the beach is also steeper (Vessey, 2003). To the south, the beach morphology typically displays a lower-gradient, sandy foreshore with distinct boundary between gravels on the upper foreshore and towards the backshore – more akin to a composite beach morphology. The generalised differences in MSG and composite beach morphology are shown in Figure 10.

**Figure 9.** (Left) North Gore Bay (approximately 100 m north of where we parked for Stop 1) looking south. Jed/Buxton Lagoon is visible on the landward side of the image. (Right) South Gore Bay looking north (Stop 2) where the beach morphology shows a distinct split between sand and gravel.

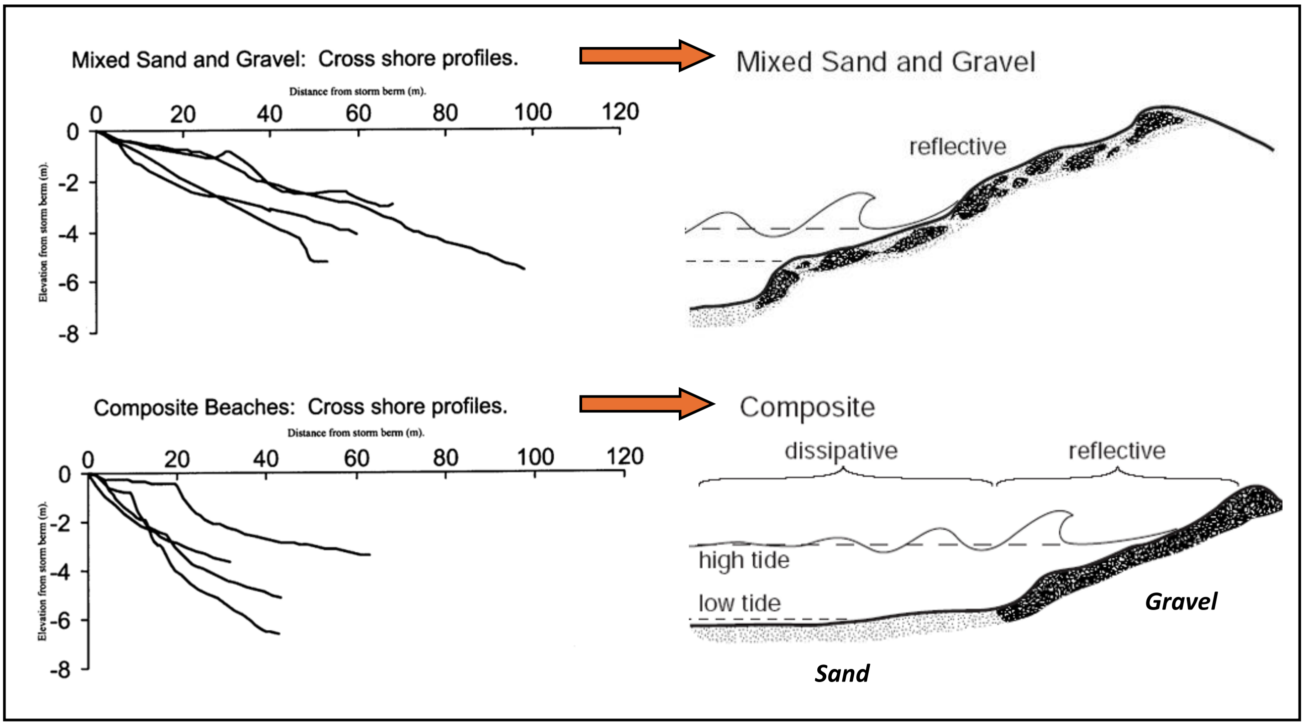


**Figure 10.** (Top) NZ MSG beach profiles and conceptual diagram of beach morphology and (bottom) NZ composite beach profiles and conceptual diagram of beach morphology (Jennings and Shulmeister, 1992).

## Coastal erosion and hazards

Some main hazards at Gore Bay include coastal inundation (including lagoon flooding), coastal erosion, tsunami, and mass movements on the hillslopes behind the township. In 2020 the Hurunui District Council commenced the “Coastal Conversations” project to identify current coastal hazards impacting Hurunui’s coastal communities and how these hazards will change over the next 100 years. For Gore Bay, the project seeks to establish a long-term approach for managing the risk of coastal hazards in partnership with the local community. This work is informed by the Hurunui District Coastline Hazard and Risk Assessment (Jacobs, 2020).

To give a befit example of some of the hazards, Figure 11 (left) shows coastal inundation at Gore Bay for a 1 in 100-year coastal storm in 2070. This includes 0.45 m of sea level rise. The deep blue shows the Jed River, Buxton Creek, and the lagoon. Flooding is expected to cover the nearby farmland, the campground and some northern properties. Figure 11 (right) shows the projected shoreline position in 2050, 2070, and 2120. As the beach barrier erodes, the lagoon area is likely to be reduced. This may increase flood risk due to the reduced storage capacity or cause the mouth to breach quicker.

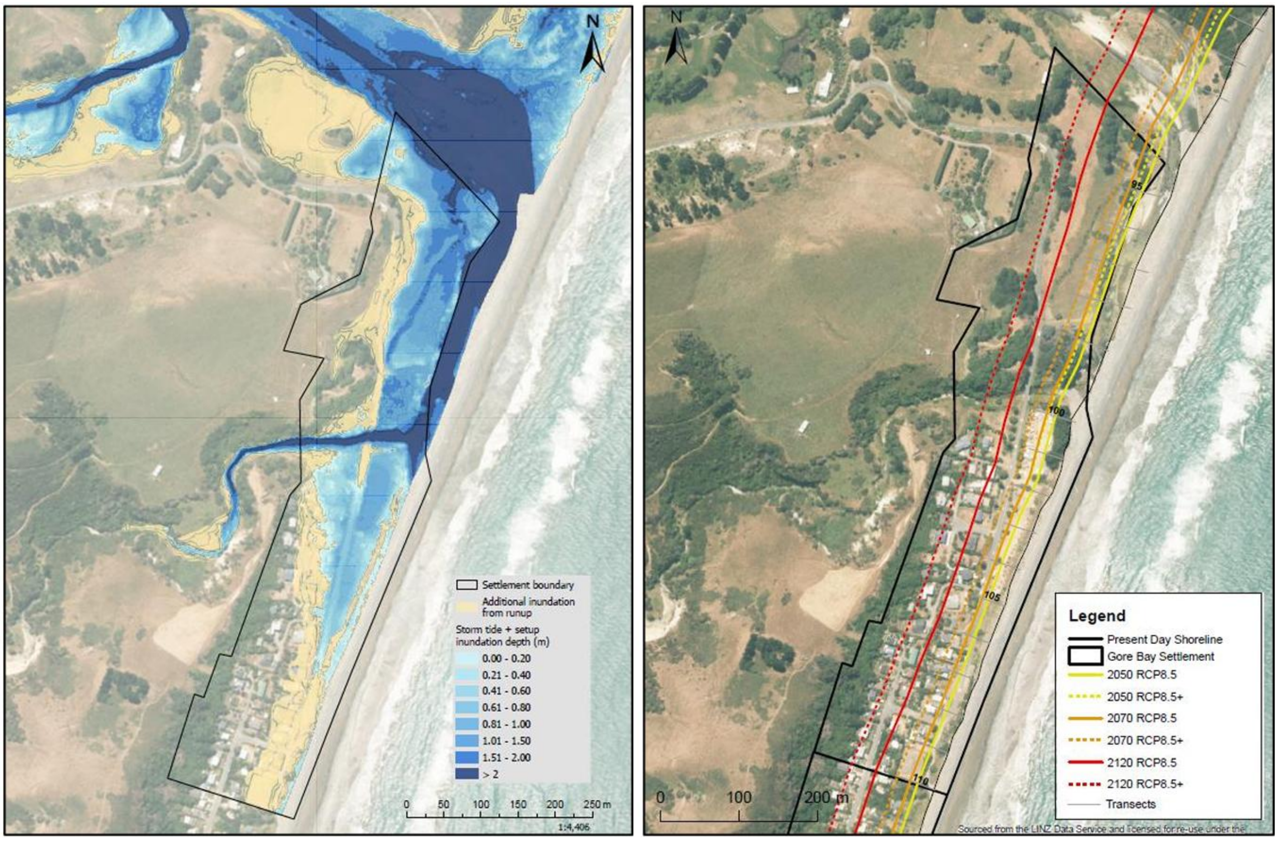


**Figure 11**: (Left) Coastal inundation map and (right) Coastal Erosion Map for Northern Gore Bay. Hurunui District Council (2023).

In the last 40 years, 15-20m of land at the seaward side of the **Jed-Buxton Foreshore Reserve** has eroded (Jacobs, 2020; Hurunui District Council, 2023) (Figure 12). The erosion is caused by the combined presence of floodwater and large seas. Big seas are likely to cause erosion in two ways:

1. When the combined river mouth is **open** water enters the river mouth and hits the bank behind the lagoon directly.
2. When the combined river mouth is **closed** water overtops the gravel bar flowing across the backed-up water hitting the bank behind the lagoon.

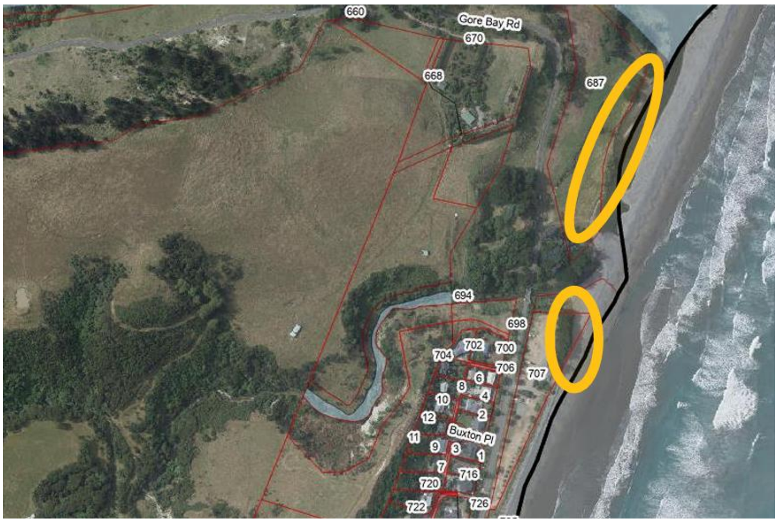


**Figure 12.** Hotspots of coastal erosion adjacent to the river mouths (Hurunui District Council, 2023).

Recent work by Somerville (2023) analysed spatial trends in shoreline change from aerial imagery record (Figure 13). The northern end of Gore Bay shows a trend of net coastal erosion whereas the southern end is accreting or stable (Figure 13). This is linked to exposure to higher energy east coast swells at the northern end, while the southern end is largely protected from the prevailing waves.

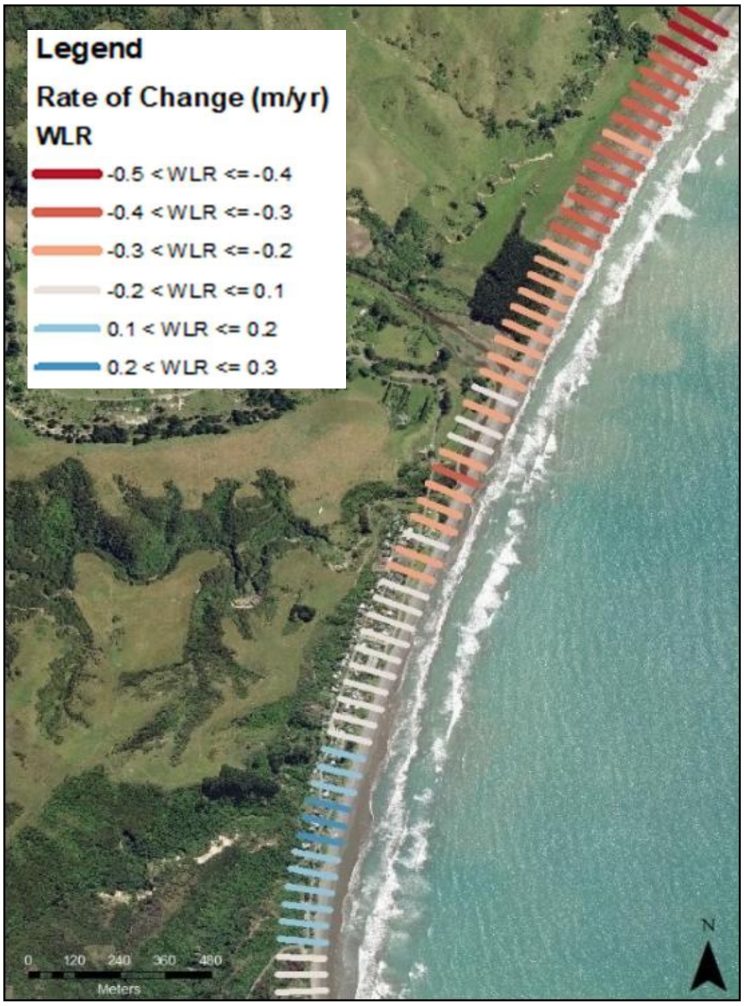


**Figure 13.** Weighted linear regression (WLR) output from DSAS showing shoreline accretion and erosion at Gore Bay (Somerville, 2023).

## Jed/Buxton Lagoon

Coastal erosion hazards are also related to river mouth dynamics and changing channel position. Gore Bay contains two permanent waterways, the Jed River and Buxton Stream, which exit to the ocean in central Gore Bay, approximately 500 metres apart. The Jed/Buxton Lagoon is an Intermittently Open/Closed Estuary (IOCE) at Gore Bay. IOCEs comprise >80 % of open coast estuaries in Canterbury (McSweeney et al., 2017). Historically, the Jed River (larger system to the north) and Buxton Creek (smaller system to the south) flowed into the sea with separate mouths.

**Decadal scale change:** Over the past 40 years, migration of the Jed River outlet channel has resulted in two rivers now flowing into a single lagoon and discharging through a common mouth across a gravel beach barrier (Figure 14). These changes have triggered erosion and inundation issues which are affecting nearby land and critical infrastructure.


**Figure 14.** Jed River and Buxton River flow paths and river mouths (Hurunui District Council, 2023).

An analysis of decadal scale dynamics using shoreline mapping and storm identification distinguished a period of high storm frequency, low rainfall and shoreline erosion from 1985 to 1988 (Somerville, 2023). These conditions align with the first signs of outlet migration visible in aerial imagery (Figure 15).


**Figure 15.** Migration of the Jed River outlet channel viewed in aerial imagery (Somerville, 2023).

**Event-scale processes:** The system's response to storm events has also been analysed in a contemporary setting during the 2023 winter season using geomorphic change detection (GCD), water level data, beach profile analyses, river flow and wave data, and time-lapse imagery (Somerville, 2023) (Figure 16; Figure 17). A conceptual model was developed based on the lagoon's response to one low energy event and two high energy events that occurred during the 2023 winter season (Figure 18). Results of the analysis confirm that the system is highly dynamic, with breach and storm events triggering cycles of erosion and recovery in the barrier (Figure 19).

This information has supported the Hurunui District Council in managing the erosion and inundation risks associated with the outlet migration. It also helps to bridge the knowledge gap on IOCE dynamics over short and long-term timescales on coarse-sediment coasts.

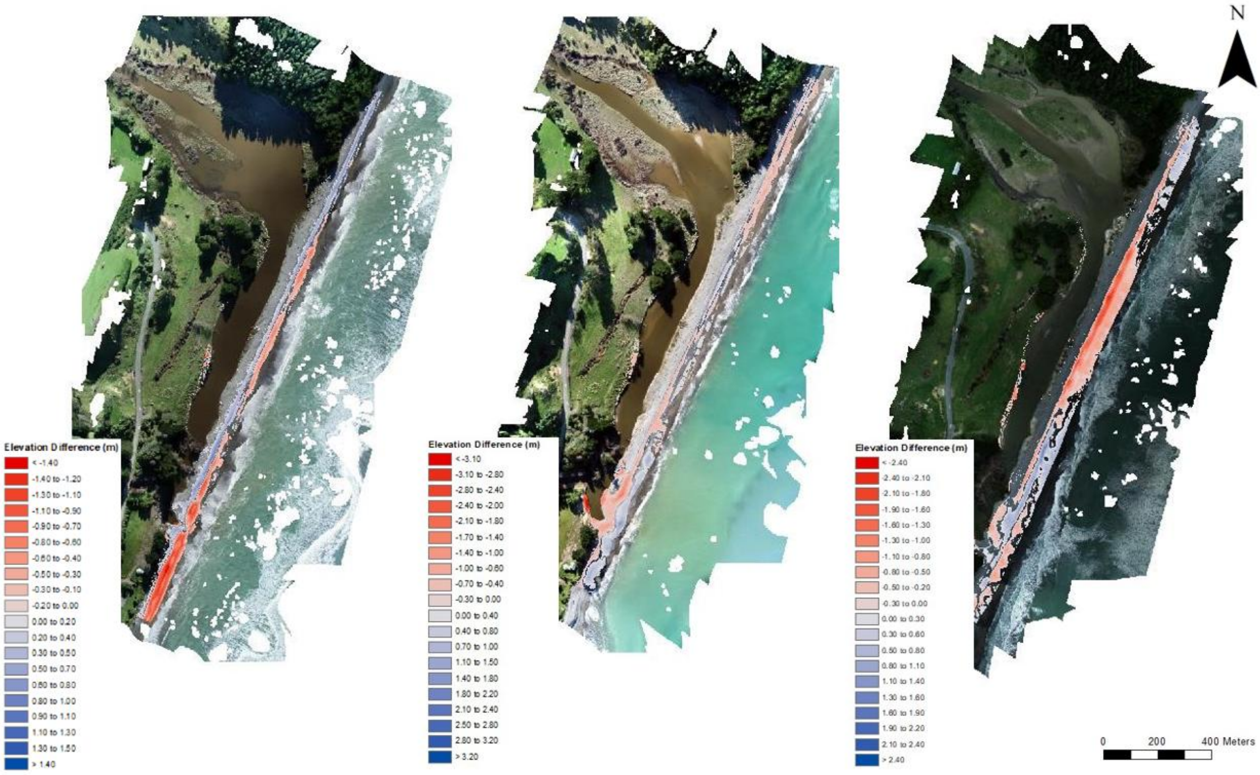


**Figure 16.** GCD analysis at the Jed/Buxton lagoon over the 2023 winter season. Left – 4th July. Middle – 18th July. Right – 6th September (Somerville, 2023).

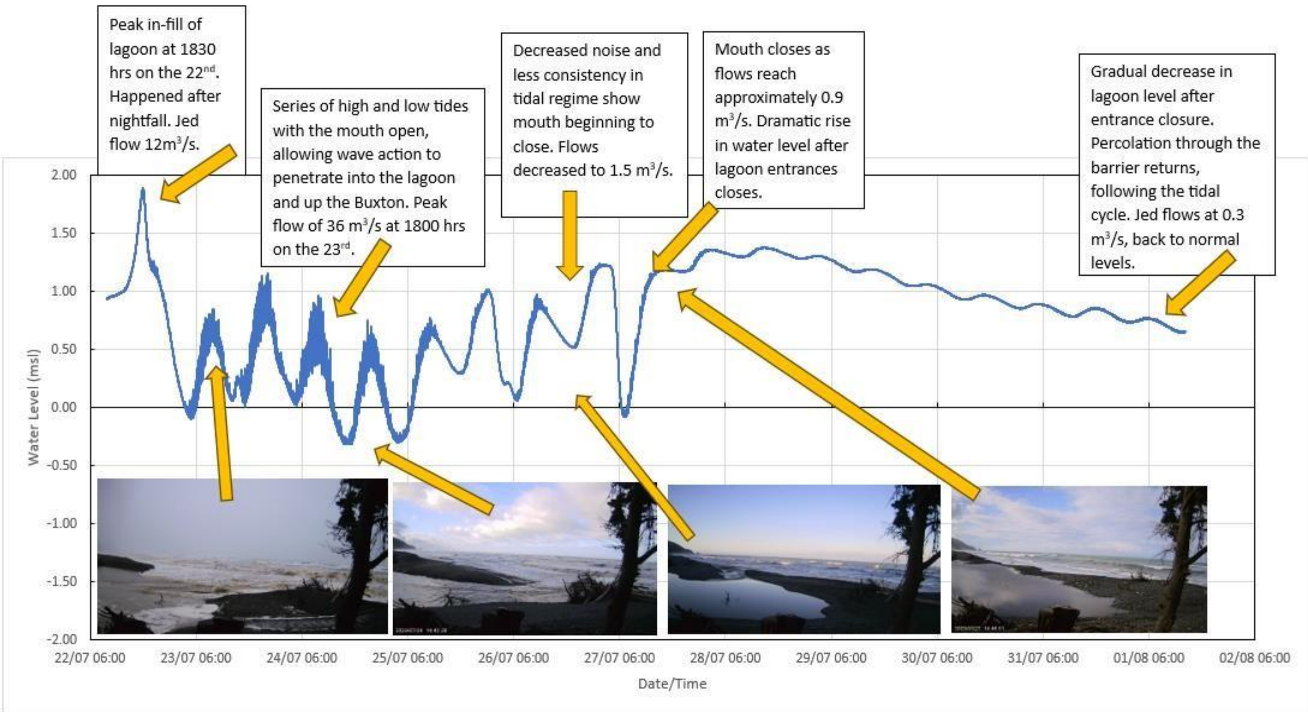


**Figure 17.** Analysis of a high energy storm event at the Jed/Buxton Lagoon, July 2023 (Somerville, 2023).

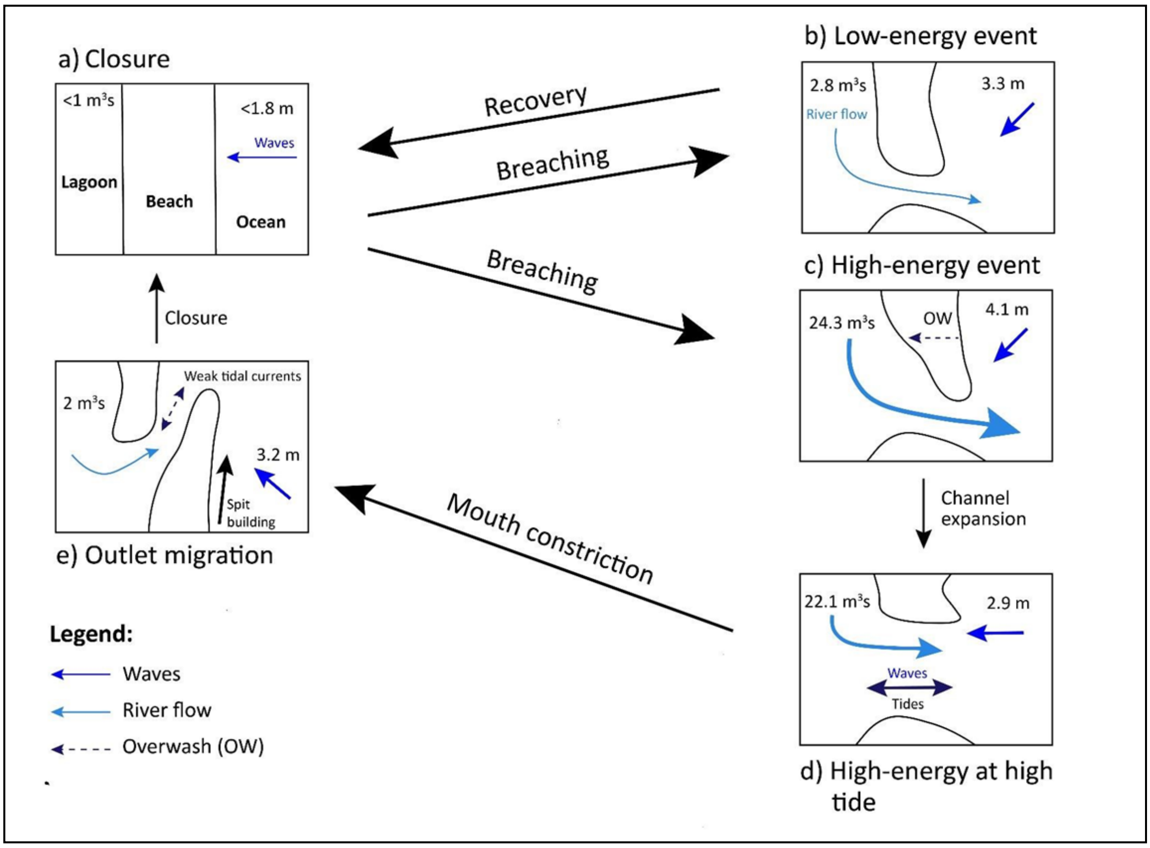


**Figure 18.** Conceptual model of the Jed/Buxton lagoon's response to low energy and high energy storm conditions during winter 2023 (Somerville, 2023).


**Figure 19.** Trail camera images capturing cycle of breaching and recovery in 2023 (Somerville, 2023).

## Stop 2. South Gore Bay

The coastline between Motunau Beach and Haumuri Bluffs is within the North Canterbury fold-and-thrust belt, a tectonically active domain near the transition between the Hikurangi subduction margin and the Alpine Fault system (Figure 20). Marine terraces in this region are imperfectly preserved along the coast, and are mostly Pleistocene-aged, although there are inter-tidal shore platforms at Point Gibson, and is south Gore Bay. The distribution of marine terraces along this section of the coast reflects the interaction between episodic sea-level highstands, spatially variable uplift, and high erosion rates. Consequently, terrace preservation and seismic chronology is patchy. Typically, a single laterally extensive terrace dominates the coastal morphology, will smaller, higher elevation, and more dissected remnants. Terrace surfaces are often obscured or modified by glacial landforms, loess deposition, and/or fluvial incision, complicating morphostratigraphic correlation.

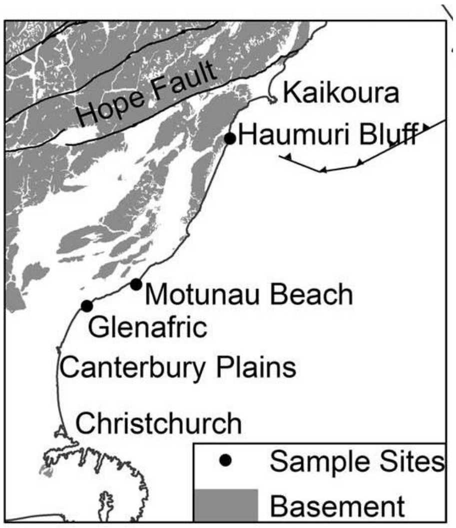


**Figure 20.** Relative location map.

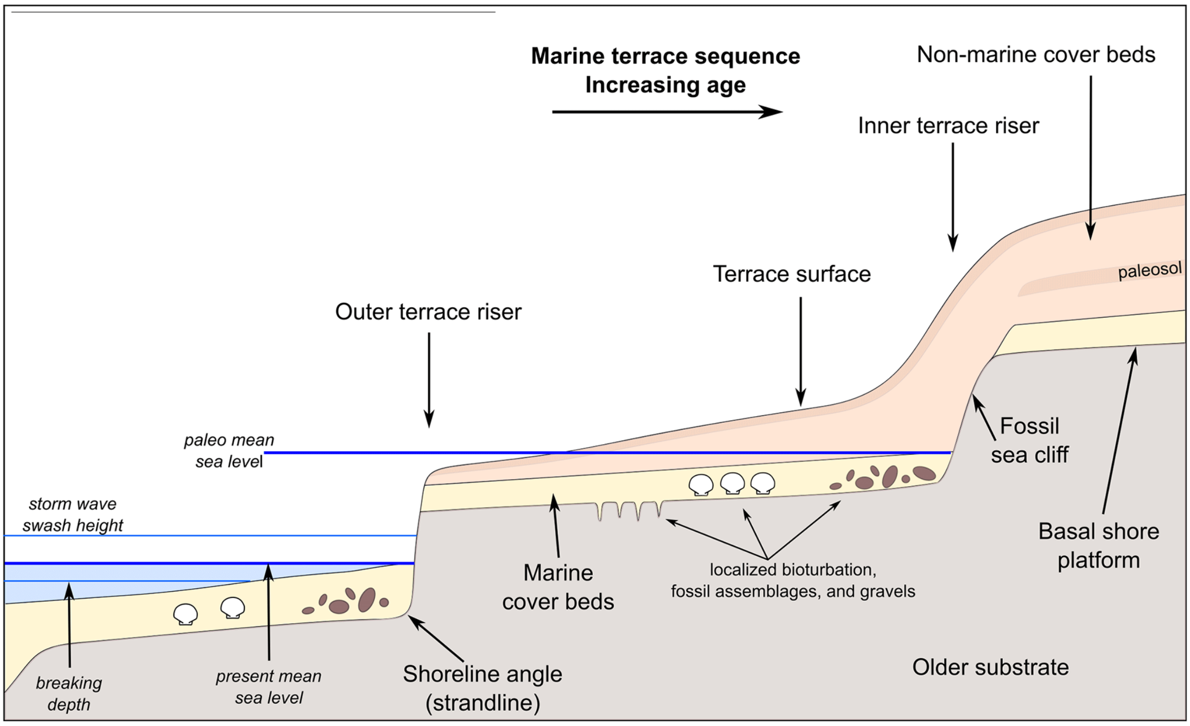


**Figure 21.** Marine Terrace terms. Source: Ryan et al. (2021).

South of Gore Bay is the Motunau Beach sequence which has an exceptionally wide marine terrace (up to 3.5 km, the widest in North Canterbury). This surface overlies a wave-cut bedrock platform and is capped by marine and terrestrial sediments of the Motunau Formation. Although the terrace appears morphologically continuous, stratigraphic and geochronological evidence demonstrates that it is composite, recording at least two phases of marine transgression rather than a single sea-level highstand (MIS 5a, ~70–85 ka and MIS 3 ~54 ka). The MIS 3 component likely reflects localized preservation during a modest sea-level rise, facilitated by rapid uplift and/or incomplete erosion of older terrace surfaces.

At the Northern end of Gore Bay, however, is the Haumuri Bluff sequence where four Pleistocene-aged terraces are preserved:

1. Tarapuhi Terrace MIS 5c (~100 ka)
2. Kemps Hill Upper Terrace (not dated)
3. Kemps Hill Lower Terrace (not dated)
4. Amuri Bluff Terrace (late MIS 5a 74 ± 9 ka)

Each terrace comprises a wave-cut platform overlain by marine cover deposits, locally interbedded with alluvial fan deposits, and overlain by loess. The terrace sequence displays systematic northward tilting, reflecting progressive deformation on the Hawkswood anticline. Notably, the Kemps Hill terraces are absent at Haumuri Bluffs themselves, but appear approximately 2 km to the south, indicating strong lateral variability in preservation.

The region has a notable absence of an extensive MIS 5e (last interglacial maximum) terrace, despite the global prominence of this highstand. In the Motunau–Haumuri sector, MIS 5e surfaces are inferred only from small, poorly preserved remnants at higher elevations. This absence is attributed to a combination of factors:

- Rapid coastal erosion, particularly during subsequent interstadials,
- Reoccupation and trimming of older surfaces during later highstands (MIS 5c and MIS 5a),
- Strong local controls imposed by lithology, wave exposure, and variable uplift rates.

At Motunau, documented historical cliff retreat of approximately 1.6 m $yr^{-1}$ since 1950 highlights the erosive efficiency of this coastline, although long-term average rates are likely lower.

## Insights from modern shore platform processes following the 2016 Kaikōura earthquake

The Mw 7.8 Kaikōura earthquake of 2016 provided a modern analogue for understanding marine terrace preservation. Co-seismic uplift of up to ~1 m instantaneously transformed active intertidal shore platforms into incipient marine terraces, revealing how tectonic forcing reorganises coastal processes and controls landform survival. From this research we have now a much better idea of the post-uplift change in process regime. For example, Horton et al. (2022) demonstrated that ~0.95 m of uplift reduced the effective intertidal width by approximately 50%, lifting large areas of former shore platform above regular tidal and wave inundation. This marked a critical preservation threshold, beyond which marine abrasion and quarrying are strongly suppressed. Uplift also reduced total onshore wave energy flux by approximately 40%, particularly attenuating infragravity wave energy, which plays a key role in long-period swash, platform wetting, and fatigue weathering. These changes highlight that marine terraces are preserved not necessarily because they are high, but because they are energetically disconnected from the coastal system. In addition, backwearing at terrace margins can remain active during storms and extreme tides, selectively truncating terrace edges and contributing to fragmentary preservation.

Dickson et al. and Horton et al. (2022) showed that this protection is also complicated by enhanced downwearing rates on newly emergent surfaces due to intensified subaerial weathering, including wetting–drying cycles, salt crystallisation, and biological activity. In softer lithologies such as mudstone, vertical lowering may progressively erase terrace morphology even in the absence of frequent wave attack. At South Gore Bay, however, the contemporary platforms are of the Pakihi or Pahau formation and a melange of sandstone and mudstone suggesting that their preservation potential is likely more complex than that observed at Kaikoura. Currently, there is no specific research published on the platforms of Gore Bay, but these landforms are intertidal features consistent with late Holocene uplift along the north Canterbury coast. Further north, around Kaikoura and to Cape Campbell there is fragmented evidence of 2–4 late Holocene co-seismic uplift events (with a periodicity ~ 500 years) (Howell and Clark, 2022).

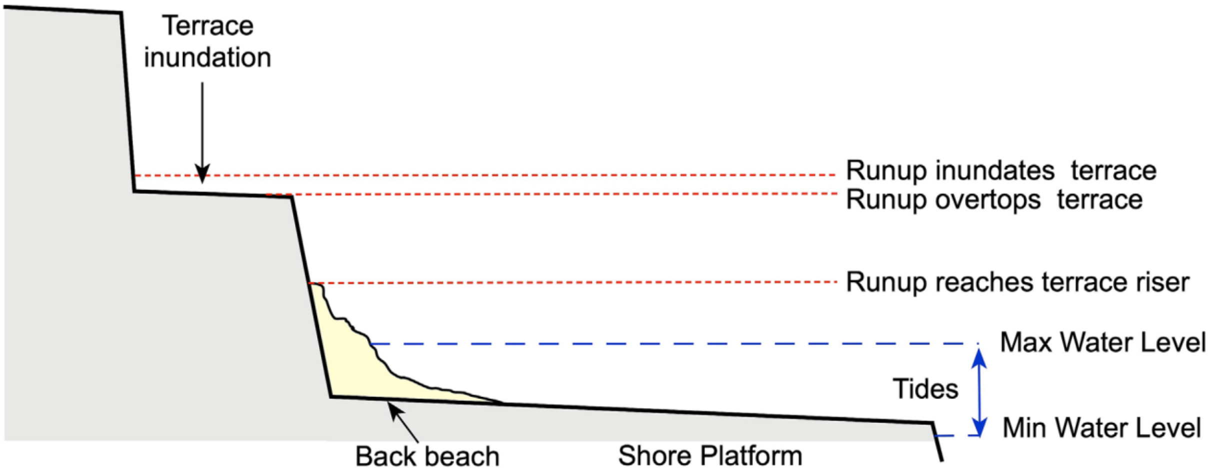


**Figure 22.** Example of terrace vulnerability to inundation after co-seismic uplift during extreme events. Source: Horton et al. (2024).

## Cliff Erosion at Haumuri Bluffs, North Canterbury

Haumuri Bluffs (also historically known as *Amuri Bluff*) is a prominent headland on the North Canterbury coast. The bluff has steep, wave-cliffed shorelines underlain by Late Cretaceous to Neogene sedimentary rocks, including mudstones and limestones, and capped by a sequence of uplifted Pleistocene marine terraces (such as the Amuri Bluff and Tarapuhi terraces). South of Haumuri Bluffs the coastline transitions from cliffs and shore platforms to narrow gravel beaches backed by **actively eroding escarpments**, suggesting sustained cliff retreat and slope adjustment in response to long-term changes in sea level, offset by co-seismic uplift (~ **1.3 mm/yr derived from marine terraces at Haumuri Bluff) within a broader long-term interseismic trend of subsidence (2–3 mm/yr).** Collectively these processes demonstrate the tectonic drivers that influence base levels and could modulate cliff erosion and terrace preservation over longer timescales.

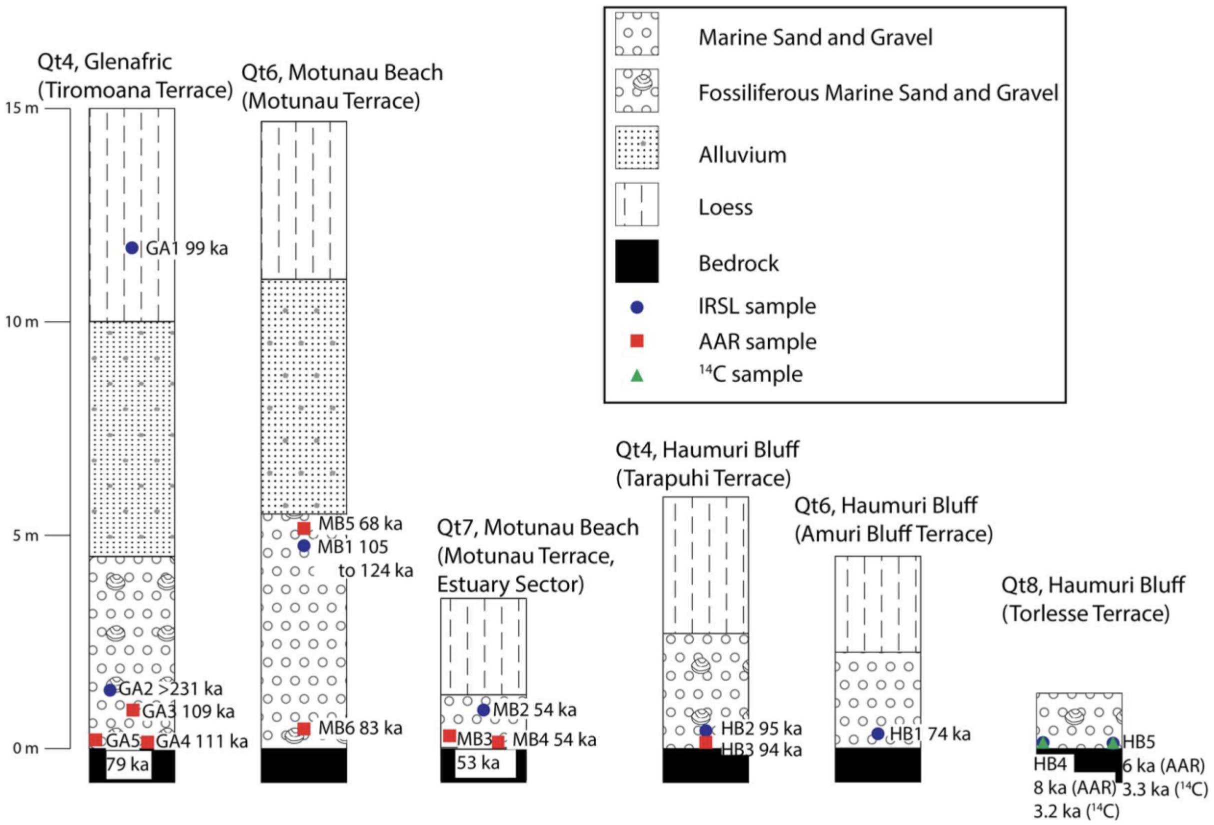


**Figure 23.** Representative stratigraphy for the marine terraces dated in this study, showing the locations of samples relative to the bedrock surface. The thickness of stratigraphic units varies laterally on each terrace, including between sample sites. Stratigraphic columns are based on Carr (1970), Ota et al. (1996), and this study. Source: Oakley et al. (2017).

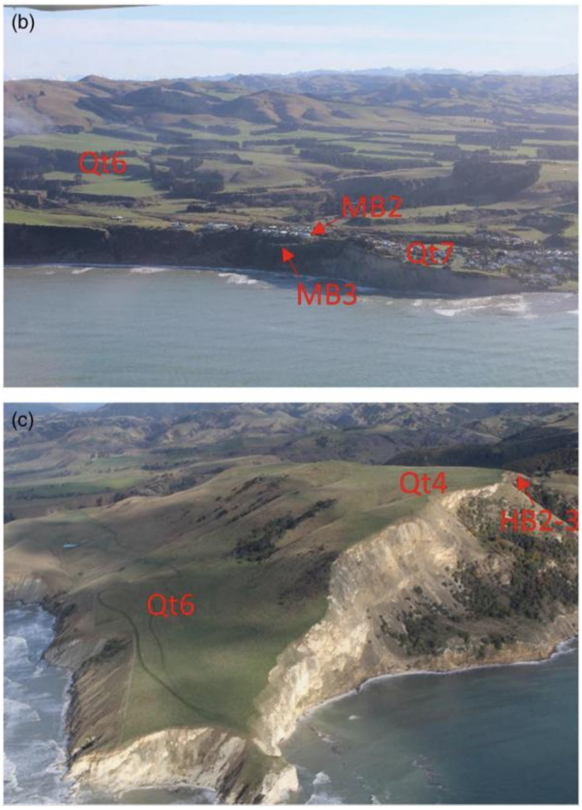


**Figure 24:** Aerial views of marine terraces at the (b) Motunau Beach view is to the west. (c) Haumuri Bluff; view is to the south. Sample sites (GA, MB, and HB) and terrace units (Qt) are labelled.

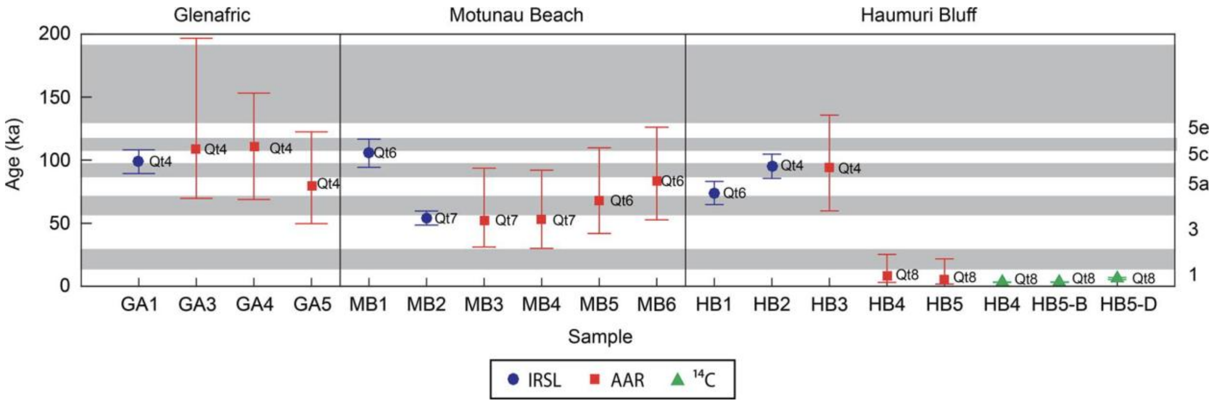


**Figure 25.** Sample age estimates for the three study areas in relation to marine isotope stages. Interstadials are white; stadials are shaded. Stage boundaries are from Lisiecki and Raymo (2005), and substage boundaries are from Williams et al. (2015). Error bars represent 95% confidence intervals for amino acid racemization (AAR) calibration curves, 2 standard errors for infrared-stimulated luminesce, and 2-sigma range of calendar-year calibrations for radiocarbon ages (14C).

## Coastal cliff lithology (from Pedley, 2017)

The cliffs at the southern end of Gore Bay expose a cross-section through shallow to deep water calcium carbonate-rich ocean sediments. The Oligocene-aged Motunau Group here consists of limestone, extensive calcareous (calcium carbonate-rich) mudstone, and with greensand at the base (Figure 26). The first unit is the shallow ocean debris-flow conglomerates in the Greta Formation, which are also seen at Cathedral Cliffs. Directly beneath the conglomerates lie the mudstones and fine limestone beds of the Motunau Group. In time, these deposits all record the ocean depth decreasing as the New Zealand landmass was lifted out of the water over the last 25 million years. The greensand is green in colour because it contains high quantities of the mineral glauconite. Glauconite is an interesting potassium-rich mineral that forms in marine sediments and can be influenced by the decaying process of organic matter with high biological activity. It is therefore most commonly found in continental shelf environments with low sedimentation rates.

**Figure 26.** Exposure of the coastal cliffs at South Gore Bay. Photo: S. McSweeney

## Stop 3. Cathedral Gully

Cathedral Gully and Cathedral Cliffs are incised erosional features developed within the soft, calcareous siltstones and fine sandstones of the Oligocene Motunau Group, which forms part of the broader sedimentary sequence exposed along the North Canterbury coastline near Gore Bay. These lithologies represent shallow-marine depositional environments, subsequently subjected to long-term subaerial exposure and tectonic uplift associated with the North Canterbury fold-and-thrust belt. There are also some harder gravel deposits as conglomerates.

The gully system exhibits steep-sided, narrow channels, with vertical relief often exceeding several tens of metres. Morphology is strongly controlled by differential erosion, where cemented horizons, gravel lenses, or localized conglomerate beds cap protect the underlying softer strata. These more resistant layers impede lateral erosion, producing pillar- and rib-like residual structures, while surrounding weaker sediment is preferentially removed. The resulting morphology is analogous to badlands, hoodoo, or clay-rich erosional landscapes described in other soft-rock terrains worldwide.

Process controls are dominated by surface hydrology. Rainfall-driven overland flow concentrates in the pre-existing gullies, enhancing incision and maintaining steep sidewalls, while episodic mass-wasting events further modify slope geometry. Soil and vegetation cover are sparse within the gully interiors, reflecting ongoing active erosion and limited sediment accumulation, whereas vegetated adjacent slopes experience reduced gullying, highlighting the stabilizing influence of plant cover on soft-rock slopes.

**Figure 27.** The Cathedral Cliffs viewpoint which overlooks an impressive series of rock pillars formed by rainwater erosion of the soft rock. Photo: K Pedley. (https://www.geotrips.org.nz/).

Cathedral Gully has been formally recognised in the Hurunui District Coastal Study as a geopreservation site of national significance, reflecting its value as a representative example of soft-rock erosion in a near-coastal setting. Its geomorphology provides a contemporary analogue for interpreting ancient marine terrace sequences and soft-rock coastal landforms elsewhere in North Canterbury, where differential preservation, lithologic heterogeneity, and hydrological concentration control the survival and morphology of incised terraces.

## Stop 4. Hurunui River hapua

Hāpua are river-mouth lagoons on New Zealand's high-energy mixed sand–gravel coasts. They differ from estuaries because there may be negligible tidal exchange (especially when presenting as intermittently closed estuaries) and are dominated by the interaction of river discharge, wave energy, and sediment transport behind coarse-grained barriers. The Hurunui hāpua is a shore-parallel lagoon impounded behind a mixed sand–gravel barrier and constrained landward by Amuri Limestone cliffs (Figure 28).

**Figure 28.** Hurunui hapua looking towards the north. Photo: S. McSweeney.

The hapua morphology is controlled by river flow variability, incident wave climate (predominantly southerly to south–southeasterly), and episodic delivery of sediment during floods (McSweeney et al., 2016). Over decadal time scales, the lagoon maintains area by a balance between barrier reworking and flood-enabled backshore erosion despite a chronically erosional Canterbury coastline.

The Hurunui hāpua alternates among characteristic states governed by flood pulses and storms:

(i) Low-energy, ponding-prone conditions with long residence times and degraded local water quality in disconnected sub-basins;

(ii) Flood-dominated conditions with rapid flushing, outlet channel enlargement, and frequent southward outlet migration; and

(iii) Storm-reworked conditions where wave overtopping/overwashing flattens barrier crests and constricts outlets without establishing sustained tidal exchange. Short-term observations and decadal aerial photography show large variability in outlet position and lagoon geometry, with area oscillating between ~102,000 and ~141,000 m² (net increase ~25,000 m², 1974–2005) and barrier width ranging ~65–86 m. The limestone backshore limits barrier landward retreat; therefore, maintenance of lagoon volume depends disproportionately on floods that erode the backshore and remove talus, counterbalancing marine overwash narrowing.

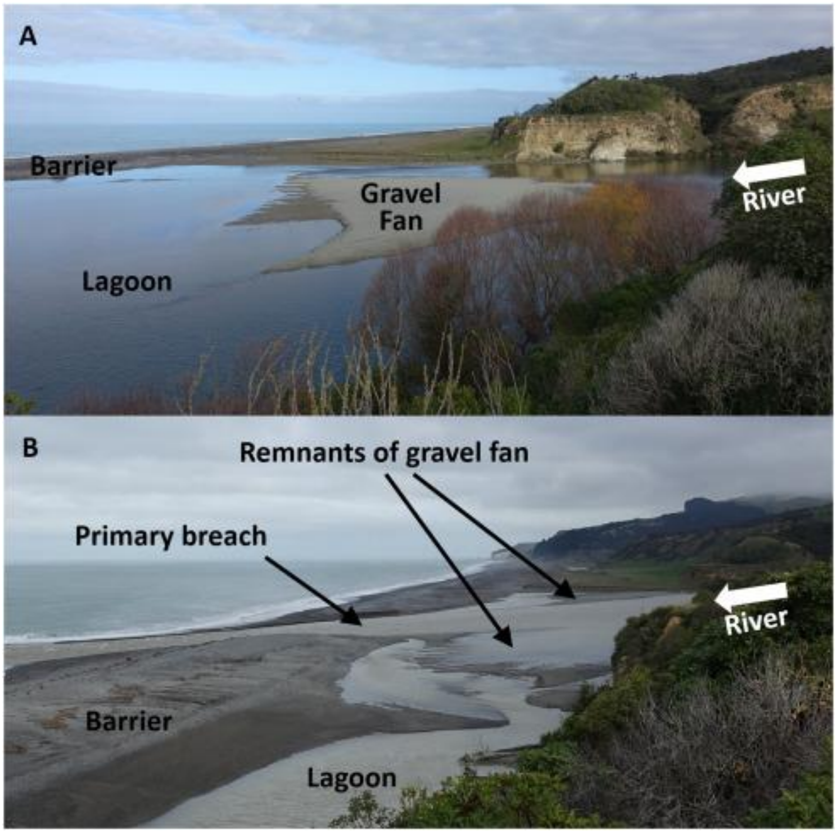


**Figure 29.** Gravel fans deposited and eroded by river floods in the south end of Hurunui hāpua. A) 24 May 2018, Gravel fan visible in lagoon during low flows. B) 15 June 2018, Erosion of a gravel fan during a primary breach. The flood peaked at 490 $m^3 \cdot s^{-1}$ two days prior to this photo. Source: Measures et al. (2020).

## Sediment dynamics and hydrochemistry

Riverine-input suspended sediment concentrations are <0.002 g/L in quiescent periods, rising to ~0.9 g/L in major floods. Fine veneers or lag deposits accumulate along the backshore after moderate floods and are scoured during large events (≥~500 m³/s). Hydrochemistry is residence-time controlled: temperature ranges from ~6–12.5 °C; electrical conductivity from ~70 µS/cm (fresh) to >17,000 µS/cm in isolated ponded sectors; dissolved oxygen is generally high to saturated (≈9–18 mg/L) and pH slightly alkaline (7.6–8.2).

## Conceptual Model of Hāpua Dynamics

Measures et al. (2020) synthesized two years of time-lapse imagery with concurrent hydrodynamic drivers to advance the conceptual model of hāpua dynamics at Hurunui. First, they distinguished between 'weak' versus 'established' barriers: post-flood onshore bar migration forms low, narrow, weak barriers that elongate rapidly under longshore transport and are vulnerable to frequent truncations. Over weeks to months, repeated overwashing and deposition build these into higher, wider established barriers that are more resistant to breaching.

Second, bar-bypassing occurs at the seaward end of the outlet through the formation of a shallow shore-parallel bar across the outlet during low flows, which periodically shortens the channel when minor wave or river events open new connections. This bar-bypassing behaviour implies alongshore sediment bypassing is a critical control on outlet migration, and consistent with modelling of river-mouth morphodynamics. In-lagoon gravel/sand accumulation at the river entry point raises bed levels and lowers the threshold flow for primary breaching, explaining variability in breach occurrence across floods of similar or greater peak discharge.

Fundamentally, three event-scale processes govern lagoon width in the short term but set long-term size through the following interactions:

(1) Wave overwashing narrows the lagoon by rolling the barrier landward and emplacing gravel lobes;
(2) River floods occurring while the outlet is offset scour the lagoon bed and banks and trim washover lobes along the backshore; and
(3) Outlet migration resets barrier position and width, locally widening the lagoon as a new, relatively narrow barrier section forms in the wake of migration.

| Process | Wave overwashing | Flood (with mouth offset) | Migration of outlet channel |
|---|---|---|---|
| Barrier width | Increases | Reduces | Reduces |
| Lagoon area | Reduces | Increases | Increases |
| Driver | Waves | River flow | Waves/River flow |
| Frequency | Approx. 6 significant events per year | Approx. 2 events per year | 1 full migration (1.5 km) in 2 years |


**Figure 30.** Key processes affecting lagoon width via time-lapse imagery taken before, during and after a typical example of each process. Notable features labelled in the images are: (A) wave overwashing sluicing gravel into the lagoon; (B) erosion of an island and the lagoon side of the barrier visible after a flood recession; and (C) narrowed barrier left behind after the lagoon end of the outlet channel has migrated past this area, with the migration direction indicated by an arrow. Source: Measures et al. (2020).

## Outlet migration and longshore controls

Observed migration rates at the seaward end of the outlet can reach ~50 m/day, predominantly northward under southerly wave climates, though southward phases occur. Measures et al. showed that once the outlet is angled in a particular direction, migration tends to persist in that direction until a substantial reversal in longshore transport occurs. Intermittent 'jumps' in both lagoonward and seaward ends—by breaching thin gravel ridges that separate the lagoon from shore-parallel channels or the channel from the sea—shorten outlet length and leave barrier islands in the lagoon. These resets modulate lagoon connectivity and water-level response, switching between 'well-connected' behaviour (tidal backwater range ~0.5–1 m with short outlets) and 'perched' behaviour (elevated lagoon levels with long constricted outlets).

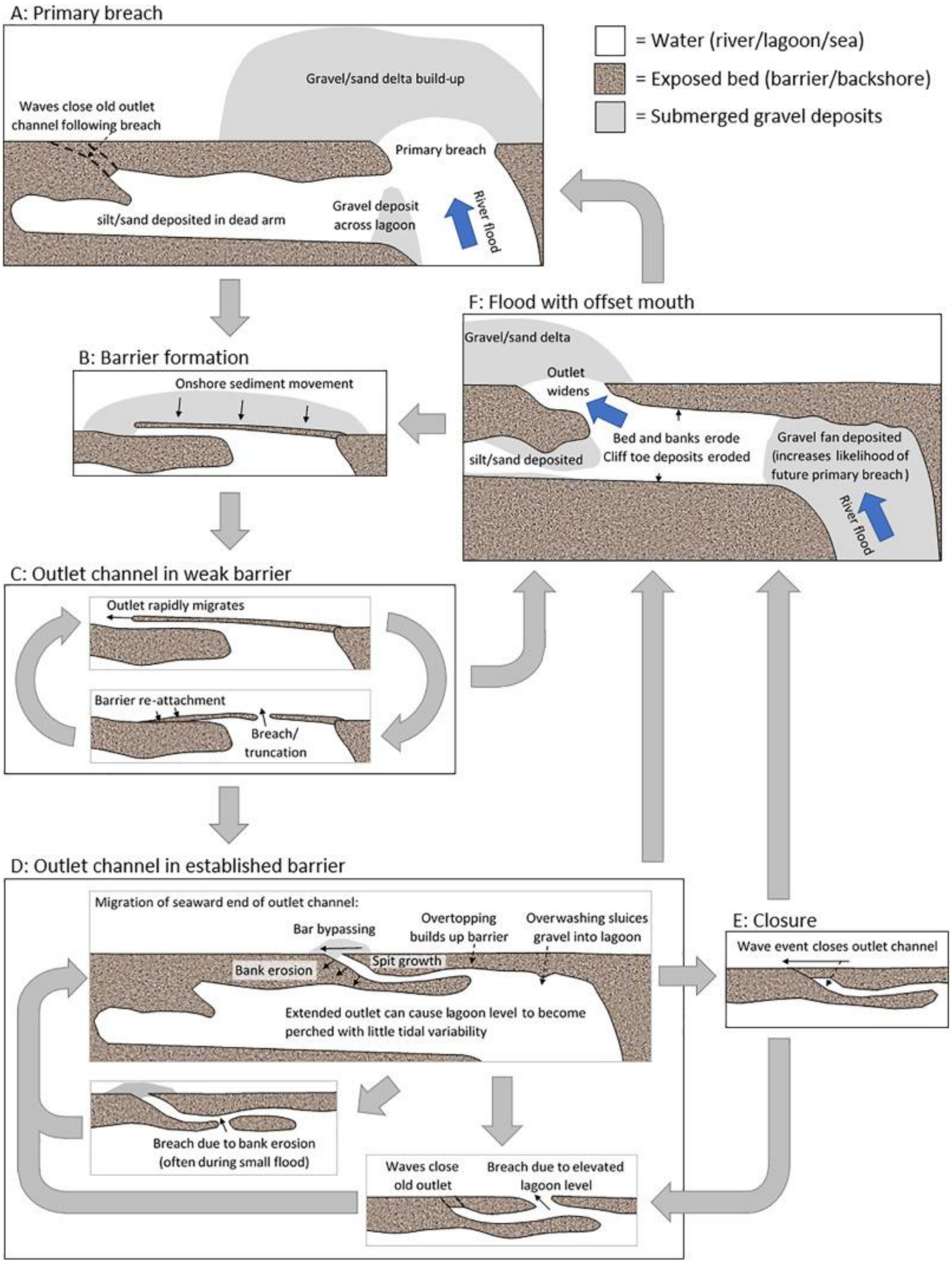


**Figure 31.** Conceptual model of hāpua behaviour (Measures et al., 2020).

## Significance for Hurunui hāpua and MSG lagoon science

The Hurunui example established that:

- Floods are functional events that deliver sediment slugs to the coast, lower breach thresholds via in-lagoon aggradation, and periodically reset outlet geometry;
- wave overwash is the dominant mechanism of lagoon narrowing between floods, with distinctive throat-and-fan overwash morphologies progressing to complete in-fill where repeated events occur; and
- outlet migration is the sole recurring process that widens the lagoon locally and is therefore essential for maintaining lagoon size over decadal scales.

These data clarify how hāpua on mixed sand–gravel coasts maintain non-estuarine states on retreating shorelines and why suppression of flood competence or longshore transport can exacerbate shrinkage, ponding, and water-quality decline.

## Stop 5. Terrace Edge Vineyard and Waipara River terraces

We will stop for an outdoor picnic lunch (pre-made for you) at the Terrace Edge Vineyard[1]. From Terrace Edge, we will have a fantastic view over the Waipara River and its terraces (Figure. 32). Staff from Terrace Edge will welcome us and give an overview of the vineyard and olive grove. There will then be an option to taste or purchase some wines, or you can just sit and enjoy your lunch and take in the view. Make sure to try the "**Liquid Geography** Riesling" which has won many awards.

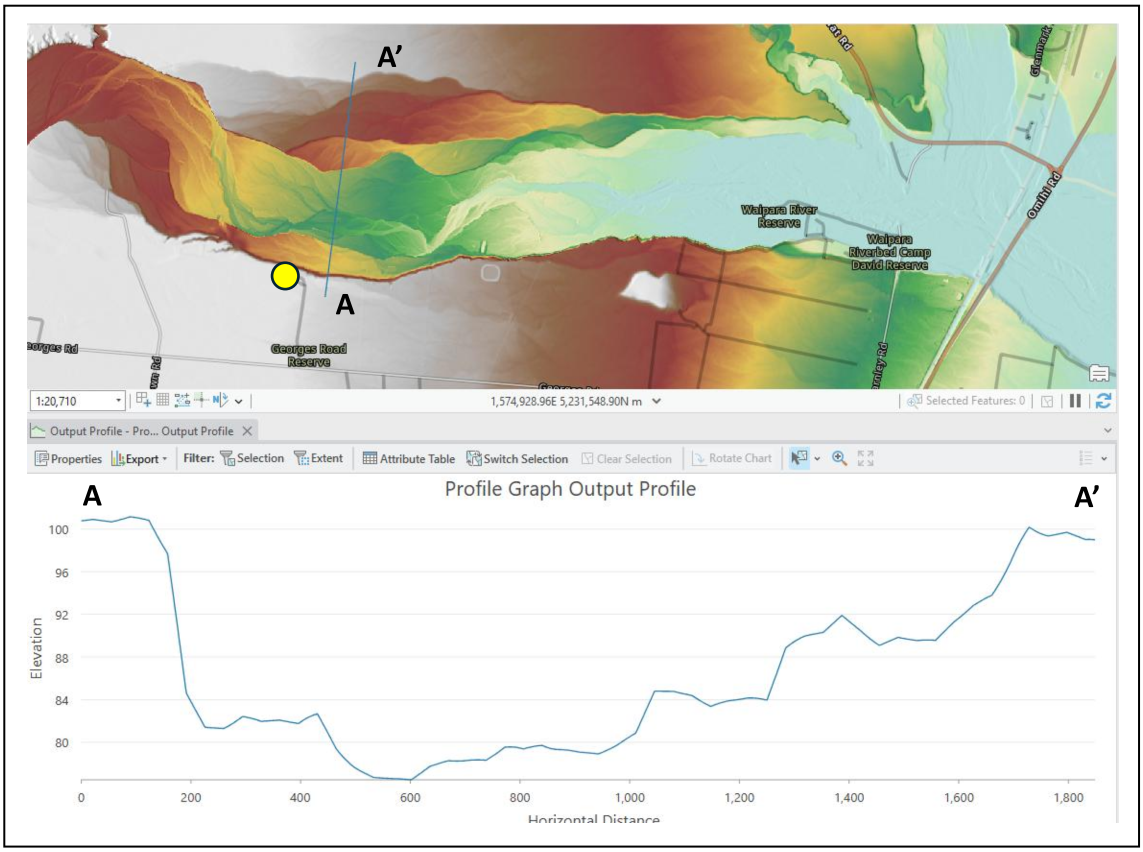


**Figure 32.** 1 m DEM of the Waipara River and terraces and extracted profile elevation graph. Terrace Edge approximate location is shown by the yellow dot.

[1] If the weather is poor, we will have to relocate to a sheltered location as we cannot all fit indoors at Terrace Edge.

The Waipara River is a relatively small river which flows for ~40 km from the eastern foothills of the Southern Alps to the sea at the northern end of Pegasus Bay. The catchment area is 726 $km^2$. Peak river flow occurs during winter months (May-Aug) and long periods of low flows are common during summer and autumn (Hayward et al, 2003). The river mouth at Waipara Lagoon intermittently closes during periods of low flow and is just north of Amberley Beach, our next stop.

The Waipara Basin and the Omihi Valley present a coherent suite of Late Pleistocene to Holocene terraces that record alternating phases of floodplain construction and channel entrenchment. The older Teviotdale Gravels and the younger Canterbury Gravels are capped by geomorphically distinct surfaces, the Teviotdale Surface and the Canterbury Surface, which together register the valley scale transitions between storage and reworking of river-borne sediment (Tonkin et al., 2015). The Teviotdale Surface is notable for its thick loess mantle, generally 2 to 3 m, within which the Kawakawa or Oruanui tephra is preserved at approximately 25ky BP. That tephra layer provides a basin wide time plane that ties terrace development to regional climatic phases and to intervals when surfaces were buried and later re-exposed by incision (Tonkin et al., 2015). The Canterbury Surface retains low relief braided bar morphology, with stony ridges and finer swales visible where agriculture or erosion has not obliterated microtopography, and this morphology is consistent with late stage floodplain construction before incision. Soil development and geomorphic relations indicate onset of incision below the Canterbury Surface in the mid to late Holocene, ~2 to 5 kyrs BP, followed by more rapid entrenchment during the last 500–1000 yrs, expressed by steep terrace scarps and regraded tributary channels (Tonkin et al., 2015).

## Tectonic uplift and climate forcing in terrace formation

Terrace geometry and gradients are conditioned by northeast trending folds that deform both Torlesse basement and the younger cover rocks into cuestas, hogbacks, and synclinal basins. Post construction tilting of terrace surfaces is recorded in surveyed segments along Mt Cass Road and Stockgrove Road, where Teviotdale treads locally slope westward and Canterbury treads slope eastward, a configuration that is opposite to the modern Waipara River gradient and diagnostic of warping after surface formation as anticlines grew (Tonkin et al., 2015). The presence of antecedent gorges where the Waipara River cuts through actively rising anticlines indicates that incision has maintained pace with uplift over extended intervals, whereas synclinal tracts accumulated aggradational deposits that were later entrenched as hydraulic conditions shifted (Tonkin et al., 2015). Inland loess is predominantly non-calcareous, while loess nearer the coast is calcareous, reflecting differences in dust source lithologies. At Mt Cass the loess stack reaches or exceeds thirteen metres and overlies upward fining valley fill resting unconformably on the marine Kowai Formation. That composite sequence records cold phase dust flux during aggradation, a subsequent episode of structural tilting, and local post tilt infill of gullies that extended the Omihi Surface down valley (Tonkin et al., 2015). On older treads such as Teviotdale and the downlands, diagnostic pedogenic horizons including fragipans, argillic Bt or Btg horizons, and deep calcic Bk horizons indicate long surface stability and characteristic water table behaviours. Younger degradational terraces carry stony Recent soils with minimal profile development (Tonkin et al., 2015).

## Linking catchment sediment production to coastal sediment budgets

The Waipara catchment delivers a mixed lithology load that includes coarse greywacke gravels and sands from Torlesse headwaters together with calcareous and glauconitic fractions derived locally from cover rocks exposed along anticlinal margins. Typical sources include Waipara Greensand and the Amuri and Weka Pass limestones, which contribute pale calcareous sands and greenish grains to terrace matrices and overbank sediments (Tonkin et al., 2015). During aggradational intervals a significant proportion of mixed load is stored on floodplains and fans as layered sequences where clayey caps overlie gravelly basal units, sometimes with intercalated or buried loessic horizons. When incision resumes those legacy deposits are re-mobilized and routed downstream, so terraces and fans function as short to long term buffers that release sediment whenever contemporary floods reach competence thresholds. Stratigraphic sections at Waipara Downs and allied fan margins reveal repeated clay veneers over gravel lenses, buried loessic Bwk horizons with vermiform macrostructure, and multi-event stacking, all of which confirm episodic storage followed by re occupation of channels across the same ground (Tonkin et al., 2015). In Omihi, the Omihi Surface overlies calcareous and glauconitic sandy gravels and includes ponded or lacustrine facies such as freshwater shells and moa bone horizons. That association indicates local base level highs and structural confinement during late Pleistocene-early Holocene transitions. The Fault Bank exposure shows progressive tilting of alluvial units dipping ~17–20º over marine Kowai strata dipping ~49º.

**Figure 33.** Oblique aerial view looking to the south-east across north-east trending valleys and hills indicating synclines and anticlines. In the foreground Weka Pass and Amuri limestones form cuestas inclined toward the centre of the Scargill Valley (Tonkin et al., 2015).

## Human land use on terrace surfaces with emphasis on viticulture

Since the 1980s and 1990s, vineyards have been sited deliberately on terraces, fans, downlands, and limestone slopes to exploit substrate controlled contrasts in drainage, rooting depth, and carbonate chemistry. On younger terrace and fan surfaces such as the Canterbury Surface and the Weka and Waipara fans, Glasnevin soils formed in fine to gravelly alluvium with minor loess present preserved bar to channel microrelief. That microrelief produces short range contrasts in vine water status and vigour between stony ridges and finer swales and is one reason these surfaces support consistent fruit quality when irrigation is tuned to microtopography (Tonkin et al., 2015). On older loess mantled treads such as Teviotdale and the downlands, govern drainage, storage, and root architecture and often require tailored ripping, subsurface drainage, and rootstock selection for viticulture. Carbonate at depth also modifies cation balances and can influence vine growth responses across blocks that appear otherwise similar in slope and aspect. On limestone slopes, like the Waikari soil types, high pH and smectitic clays combined with variable stone content to create strongly site specific performance for vine growth, which must be addressed by rootstock selection and canopy management. Thus, across the Waipara basin there is distinct pedological differences that affect fruit quality, flavour and viticulture success.

**Figure 34.** Waipara River with gullies eroded into older fans (left) and terraces incised below the Canterbury Surface (right) (Tonkin et al., 2015).

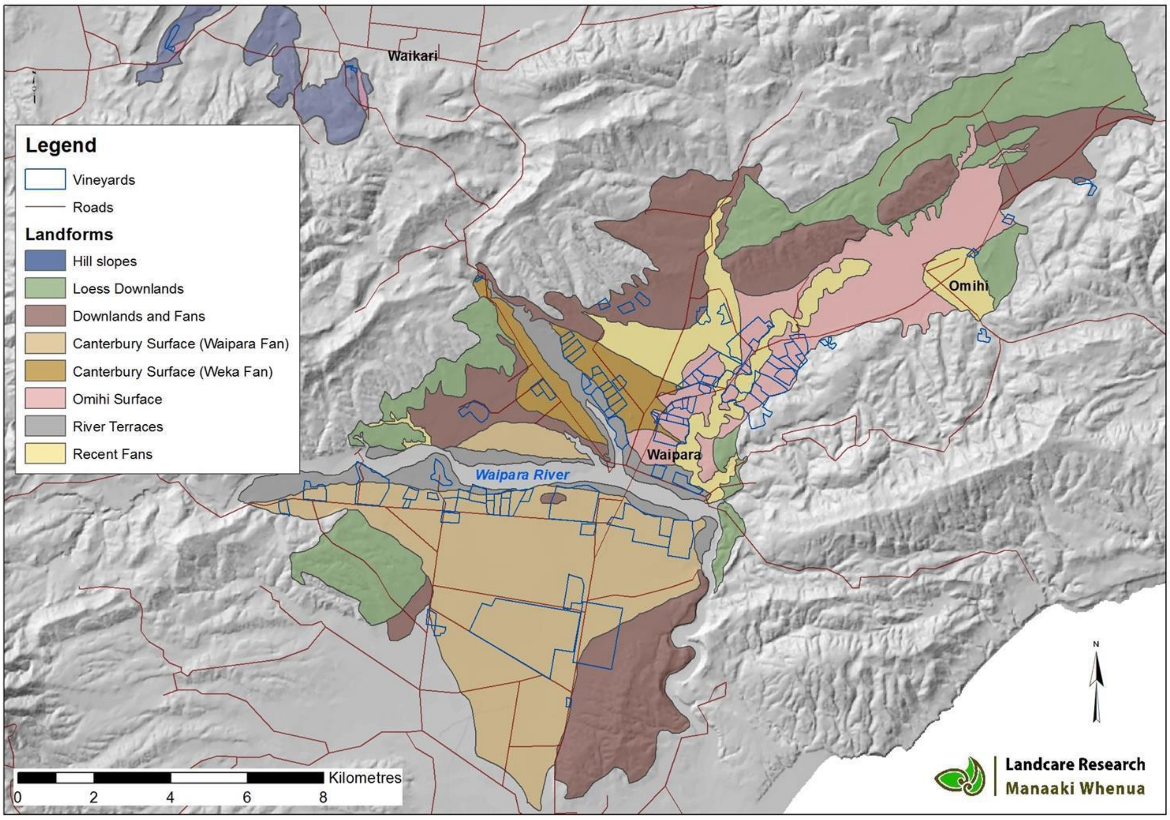


**Figure 35.** Landforms associated with wine growing in North Canterbury (Tonkin et al., 2015).

## Stop 6. Amberley Beach

Amberley Beach is a small township in Northern Pegasus Bay experiencing severe coastal erosion. For the last 20 years, a man-made bund located on the storm ridge of the beach has successfully prevented inundation of the settlement in coastal storm events. However, the bund has suffered erosion in significant storm events resulting in several nourishment top-ups being required to maintain the design level of flood protection (Figure 36).

**Figure 36.** (Left) Bund reconstruction at Amberley Beach and (right) water washing over bund. Images from: S. McSweeney and Hurunui District Council (2023).

In addition to erosion, the settlement is exposed to flood and inundation hazards (Figure 37). To the south and north of the town, there are two coastal lagoons - Mimimoto Lagoon (south) and Amberley Beach Lagoon (north). Neither of these lagoons have a permanent opening to the sea, with their outlet channels normally blocked by beach sediment. This prevents the regress of high lagoon water levels but allows the ingress of sea water during coastal storm events, both which add to the flood hazard. Rising groundwater and fluvial and pluvial flooding add to the inundation risk.

**Figure 37.** Inundation event at Amberley Beach showing ponding of water on low-lying land and lagoons image from Hurunui District Council (2023b).

Some estimates of future erosion and inundation scenarios are shown in Figure 38 below:

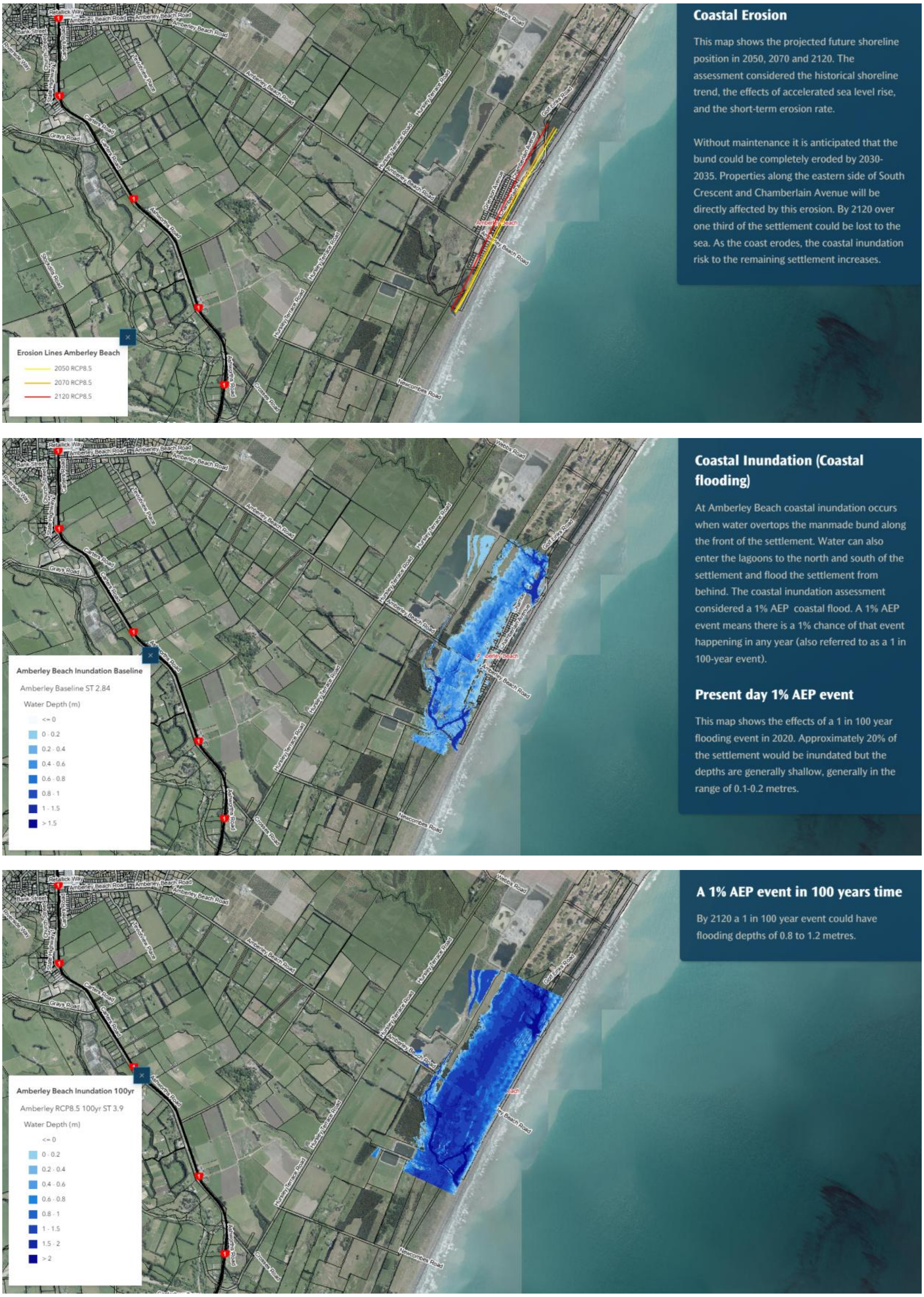


**Figure 38.** (Top) Projected future shoreline change under RCP8.5, (middle) present day 1 % AEP inundation event, and (bottom) 1 % AEP event in 100 years time (Hurunui District Council, 2023b; Jacobs 2022).

Rising groundwater will add to the inundation risk from sea level rise. The groundwater table in the area is quite shallow. Predicted change from today to 2120 are shown in Figure 39.

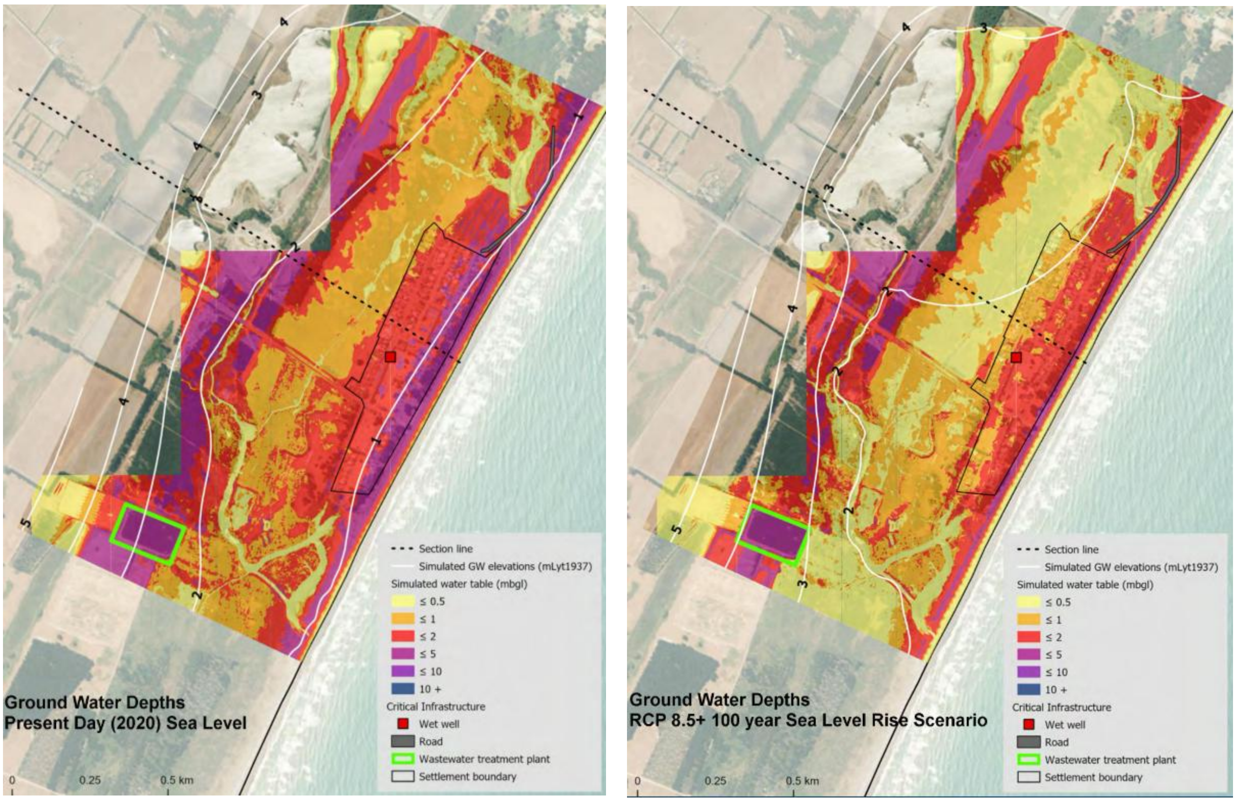


**Figure 39.** Changing groundwater elevations from 2020 to 2120 (Hurunui District Council, 2023b).

Hurunui District Council commissioned Jacobs in July 2021 to undertake an investigation of potential physical erosion and inundation management options that could form part of Amberley Beach Coastal Adaptation Plan. Jacobs developed an exhaustive 'long-list' of potential mitigation options, which through a high level options assessment reduced this long list to a 'short-list' of options at each settlement for conceptual design and indicative costing. Potential recommended short-list management options were presented to the community and were explored by the communities in a facilitated workshop environment.

**Kate MacDonald from Jacobs** will speak to us about the project, management options, and engagement with the local community.

Student MSc research at Canterbury University is also investigating links between changing fluvial sediment budgets on the Waipara River (north of the town) and coastal erosion at Amberley Beach.

## Stop 7. Ashley River estuary and dunes (time permitting).

The Ashley-Rakahuri is a braided river catchment located in the foothills of North Canterbury (Barlow 2022). The headwaters are in the Puketeraki range before flowing through Lees Valley, the Ashley Gorge, and the Canterbury plains north of Rangiora before entering the Pacific Ocean north of Waikuku (Sutherland 2006). The catchment area is 1340 km$^2$, the length of the river is approximately 95 km and there is a riverine elevation change of 1000 metres (Sutherland 2006). The river has a mean annual flow of 13 m$^3$s$^{-1}$ and a coefficient of variation of 1.6 suggesting catchment characteristics dominated by irregular flow fluctuations between strong flood activity with high geomorphic capacities and irregular precipitation (Duncan 1992; McKerchar et al., 1998). The highest river flow occurs in winter, typical of a sub-alpine catchment missing the significant impact of storage as snow.

There are significant alluvial gravel deposits, covering all low gradient slopes within the catchment. The Ashley Rakahuri catchment is predominantly braided within the open plains and valleys of lesser slope and shows natural channelization and confinement of varying degrees within the steep alpine and gorge reaches. It's only within the unconfined valley basins and plains where the braided reaches and alluvial gravel deposits are present. There is a clear correspondence between soil depth and river path with a clear reduction in soil depth in the riparian areas of the main tributaries within the catchment, highlighting the geomorphic control of the river on surrounding area. The most dynamic areas and therefore with the greatest propensity for morphological change within the Ashley Rakahuri catchment are within the plains and valley bottoms reflected by large alluvial deposits, unconfined river morphologies and shallow soil depths within the low slope gradient areas.

The Ashley Rakahuri enters Pegasus Bay through a dune capped sandy barrier (Figure 40). The barrier is dynamic and shifts position during floods – often creating multiple outlets. The area is a significant habitat for native species and is culturally important for Maori people.

**Figure 40.** Images showing the barrier and estuary morphology and delta prograding into the Ashley-Rakahuri lagoon. Photos: S. McSweeney.

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