# Changes in the Rakaia River mouth barrier dynamics.

In association with Bill Southward and the Rakaia Community.

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# Executive Summary

This study investigates the evolution of the Rakaia River mouth barrier, the processes influencing its morphology and position, and its impact on the local Rakaia Huts community. This is done by analyzing 30 years of beach profile, river cross-section, and marine/fluvial data. Analysis of LiDAR using Arc GIS Pro along with data manipulation and presentation in Excel was used to enhance our understanding of barrier dynamics. Additionally, statistical analysis of time series data using R Studio and Excel allowed us to examine the influence of various factors such as river flow, wave action, sedimentation, and storm events, on the barrier's erosion and sediment transport patterns.

Our findings revealed a significant shift in the barrier's positioning over time. Between 1991 and 2008, the barrier exhibited progradation of 134 m, advancing towards the sea. However, since 2008, it has undergone a notable retreat of 60 m. Meanwhile, the beaches on either side of the barrier have continued to prograde, highlighting the complexity of coastal processes and likely interplay of sediment transport from the river to the coast. These findings have significant implications for flood management practices and community planning in the Rakaia Huts region. By understanding the historical and ongoing changes in the barrier, local authorities can make informed decisions to mitigate potential risks and safeguard the community. This research contributes to our broader knowledge of coastal barrier systems, particularly the complex interaction of hydrological and coastal processes under both natural and human-induced influences.

While this study does provide valuable insight, it is essential to acknowledge limitations. The reliance of the study on pre-collected data may have restricted the accuracy of the analysis. Future research could benefit from real-time data collection, or at a more sub-annual temporal scale, and the use of advanced techniques like drone-based aerial imaging and repeat LiDAR to ensure the data is accurate.

In conclusion, this study identifies the timing and drivers of key shifts in barrier position for the Rakaia River mouth barrier. Increased knowledge and a thorough analysis of its evolution contributes to the current understanding of the hydrological and coastal processes shaping the barrier, and implications for the local community.

# 1.0 Introduction

Bill Southward has requested research to investigate the everchanging environment at Rakaia Huts River mouth. This will allow Bill's years of data collection to be published into a useful document that should assist in flood management and community understanding.

The study site consists of a hapua formed at the mouth of the Rakaia River where the interaction between the river flow and coastal process creates an elongated water body parallel to the coast separated from the sea by a gravel barrier. On the terrestrial side of the hapua lies the infrastructure of the Rakaia Huts community, such as housing and a camping ground, both of which hold cultural significance to the Mana Whenua.

The Rakaia River and hapua are significant to the Rakaia Huts community, however flooding here occurs regularly. Extreme flooding events influenced by hydrology cause significant erosion and alteration to the river mouth and the barrier system (Browne, 2002; Horrell et al., 2012). Wave action further intensifies the challenges that face the community. The interaction between wave action and the dynamic river mouth can heighten the erosion rates and shift the sediment deposition patterns.

The dynamic nature of the barrier and subsequent flooding presents many challenges to the community of Rakaia huts, as the barrier is an important storm buffer for the local community and their infrastructure. Understanding long-term changes in its position is crucial to the longevity of the Rakaia community. Therefore, our project aims to:

1. Identify any significant change in the barrier and beach profile over the last 30 years.
2. Aid our findings using river flow and wave height and riverbed level data.
3. Understand how these changes have impacted on the local environment.

The effects of flooding at Rakaia Huts are becoming more prevalent, but there is a significant knowledge gap regarding how these patterns have evolved. This research aims to track changes in the barrier and coastline and link these to wave and river flow data, to help the Rakaia Huts community better understand the past and anticipate future risks. The findings could also benefit the Selwyn Rescue Management Group, the Rakaia community, Environment Canterbury (ECAN), and the Selwyn District Council in future planning efforts.

## 1.1 Background

The Rakaia River mouth is located south of Rakaia Huts in Canterbury, New Zealand (see Figure 1). The river mouth forms a hapua formed due to the interaction between the river flow and coastal processes creating an elongated water body parallel to the coast, separated from the ocean via a 3km long barrier (Kirk and Lauder, 2000) (see Figure 2). The Rakaia huts community holds residential housing, camping ground, boat ramp and is home to 85 permanent residents, plus 200 seasonal residents (Witter, 2008).


Figure 1. Map of Canterbury New Zealand, in relation to the study site.

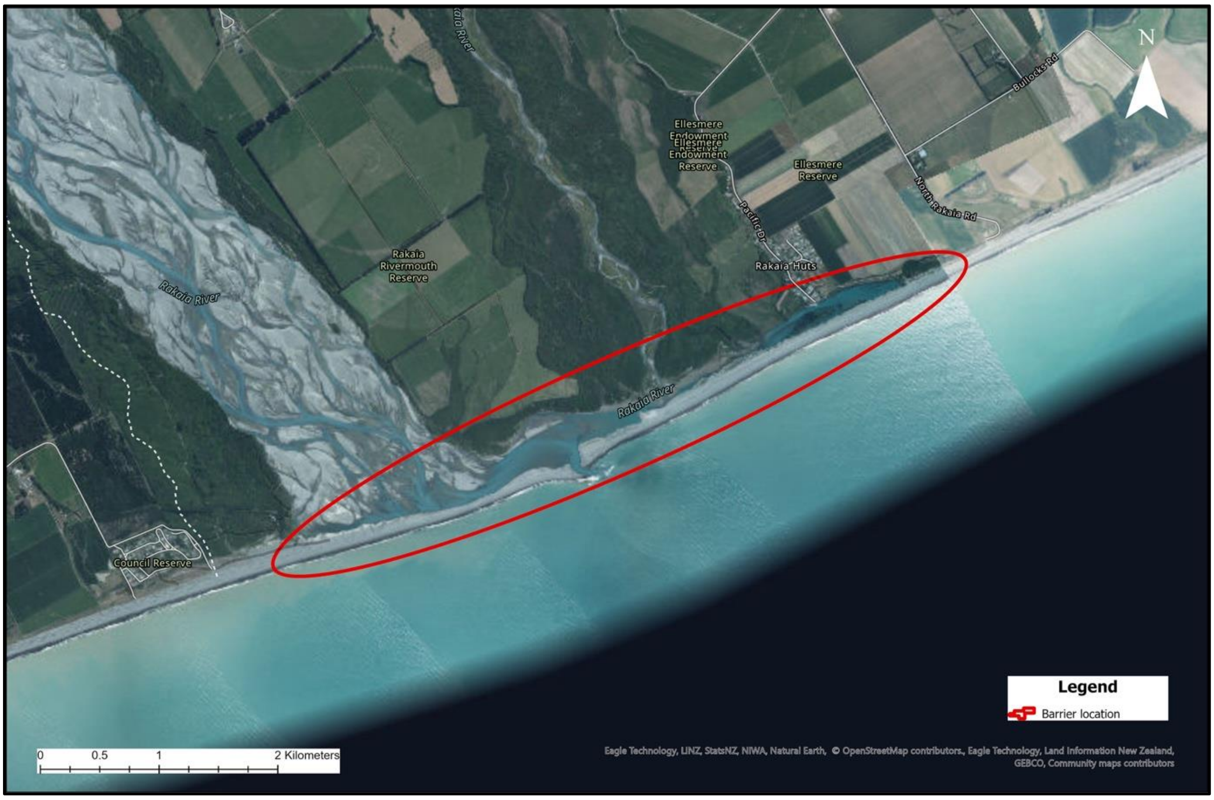


Figure 2. Map of Rakaia huts and the Rakaia River Mouth and hapua. The barrier is circled in red.

## 1.2 Context

Understanding the significance of the barrier and river mouth as environmental, cultural, and social components for the Rakaia community is crucial for completing this study. Through existing literature, four key areas have been highlighted, showing the importance of the barrier and river mouth in upholding the history and cultural significance of the site, as well as its role in hydrology and flood management.

The Rakaia River holds a deep history, forming via glaciation processes around 2.6 million years ago, shaped by cycles of glacial advance and retreat (Burrows, 1977) (Soon, 1963). The Rakaia River's current braided structure was formed during the last glacial maximum, which scoured out the Rakaia valley and deposited large amounts of sediment (Speight, 1934). The ongoing interaction between the river flow and coastal forces constantly reshapes the river mouth and hapua (Kirk & Lauder, 2000).

Māori settled in the Rakaia area around 1300-1400, quickly forming a deep connection with the river (Witter, 2008). The river is considered a taonga (treasure), and it holds spiritual significance, offering an abundance of resources essential for early Māori. The ocean nearby also offered valuable kai moana (seafood) (Environmental Canterbury, 2024). Māori developed sustainable practices to manage these resources, which also influenced their settlement patterns (NZ Ministry for the Environment, 2020). Additionally, literature highlights Rakaia as a significant archaeological moa hunting precinct that should be preserved (Witter, 2008) (Teviotdale, 1939).

Sediment transport within coastal environments of the Rakaia River are influenced by different factors. These are the transport of sediment being carried from upstream and coastal erosion from waves. Both sediment dynamics and coastal erosion are influenced by both human and natural factors. Natural drivers, especially ones that are primarily driven by climate change, can include sea-level rise and extreme weather events like storms and flooding (Caruso et al., 2013). Also, the climate change impacts on snow in the Southern Alps have also led to increased river flow, which has influenced the sediment load moving downstream (Matthew & Bright, 2003). Finally, certain agricultural practices around the Rakaia River have caused changes in sediment flux. When cattle are grazed along the riverbanks it can cause the banks to collapse, introducing sediment that is carried downstream to the river's mouth (Tait & Cullen, 2006).

The wave action at coastal interfaces is an important process that happens at both the barrier and the river mouth of the Rakaia River (Masselink et al., 2011). This is due to the wind influence on wave action can affect both stability of the barrier and the topography, and wave energy can increase cases of erosion and cause an increase in sediment transport at both the barrier and the river mouth (Brocchini, 2020). Large storm events can further amplify these processes over shorter temporal scales (Masselink & van Heteren, 2014).

Wave over-washing is an important process that is impacting the Rakaia barrier and *hapua*, as wave action increases sediment erosion from the seaward barrier face and causes deposition on the landward side of the barrier, influencing the barrier dynamics (Matias et al., 2011).

Therefore, this causes barrier rollover and migration inland or the drowning of the barrier (Orford et al., 1991). The amount of sediment available affects the barrier's ability to migrate inland during over washing. Sediment must be transported from both behind and onto the barrier to promote migration and prevent the drowning of the barrier (Lorenzo-Trueba & Ashton, 2014). However, with globally increasing sea levels, more barriers are expected to drown in place as sediment supply cannot keep pace with the sea-level rise induced overwashing (Lorenzo-Trueba & Ashton, 2014).

Extreme flood events, such as the January 1994 flood and the December 2010 storm, have largely affected both the hydrology and ecology of the Rakaia River. The 2010 storm brought about 350mm of rain, causing one of the highest recorded river flows and expanded flood channels to about 400 meters wide. This led to increased erosion along gravel beaches (Horrell et al., 2012). The 1994 flood had a peak discharge of 5595 cubic meters per second that caused large amounts of coastal erosion, reshaped riverbanks, and reduced clast sizes downstream (Browne, 2002). These large flood events have damaged riparian vegetation, salmon migration routes and different aquatic habitats like fish spawning beds. This has also impacted groundwater recharge and wetland ecosystems (Unwin, 1997). As the increase in sediment deposition from these floods has changed ecosystems by reduced water quality, it has also buried aquatic habitats and shifted species distributions (Horrell et al., 2012; Hicks et al., 2020). Overall these extreme weather events have a large impact on the ecology and physical structure of the river.

## 2.0 Methods

The study analyses datasets collected over the last 30 years to investigate barrier position and migration at the Rakaia River hapua. The data included both beach and barrier profiles, riverbed cross-sections, river flow data, wave buoy information, and sediment dynamic. Much of the data was initially gathered by Bill Southward, with additional records like acquired from ECAN and National Institute of Water and Atmospheric Research (NIWA).

Barrier and beach profiles from three locations (south of the Rakaia River mouth, at the barrier, and north of the Rakaia River mouth) (see Figure 3) were accessed through Environment Canterbury. They were imported into Excel, and a visual map of the locations the surveys were taken along the coastline was created. The data was then adjusted to the Lyttleton 1937 local vertical datum for consistency. Barrier/beach profiles were then plotted in Excel, and a graduated colour ramp was used to highlight the physical differences to the coastal envelope of change over time.

River flow data was collected from the Fighting Hill stream gauge by NIWA. The data was first imported into excel, where the mean daily flow was calculated, then plotted as a time series graph spanning from 1991 to 2023. Time stamps of the barrier surveys were added to the river flow graph to add a visual representation of the survey timing. Flow rates were then statistically analysed using R Studio and an ANOVA test was run the study period is from 1991 to 2023, which determined the significance in changes to the river flow.

Wave data used was accessed from the ECAN/NIWA wave buoy (located 17km east of Le Bons Bay, at a Latitude 43° 45' South, Longitude 173° 20' East), as well as the hindcast wave model (1993–2019) (Hanson et al., 2009) and both were processed using Excel. The mean daily wave heights and directions were then calculated and plotted into a wave directional rose and two time series graphs. A wave threshold was set at the 95th percentile to identify any critical events. The use of wave thresholds, as discussed in Mortlock and Goodwin (2015), was applied to help identify critical wave heights with a major geomorphic impact on coastal processes such as sediment transport and erosion. The time stamps of the barrier surveys were added to the wave time series graph to add a visual representation of the survey timing.

Riverbed elevation data from NIWA (1989, 2010, and 2023) was processed using Excel, along with LINZ LiDAR (2015) digital elevation model data which was imported into ArcGIS along with the existing riverbed profile transect. Data from the 2015 dataset was then extracted along the transect and converted to the LDV37 datum to match existing datasets. The riverbed levels of each of the four years were then plotted on one line graph using excel to easily visualise any changes occurring along the same cross-section.


Figure 3; Position where the data was collected for both barrier and beach profile

# 3.0 Results

**3.1 Results – Barrier position and morphology**

The Rakaia hapua barrier has experienced significant variability since 1991 in terms of its position, and morphology, although the overall change since around 2016 has been minimal (see Figure 4). The barrier position, taken by recording the location of the crest or highest point of the barrier, has shown considerable migration over the research period. Between 1991 and 2006, the barrier crest significantly prograded 134m seaward (0.0143) (see Figure 4). Since 2006, the barrier has significantly retreated landward 60m (p-value of 0.00497), however most of this change happened prior to 2016. The height of the barrier has also evolved. Despite standing around 5.5m above sea level (asl) in both 1991 and 2024, it fluctuated between 5.7m and 3.5m during the 30 year study period. Finally, the shape of the barrier has also evolved. Since around 2016 the barrier has maintained a unimodal shape, however previously to that it has shown a number of different shapes with multiple crests, the most obvious example being the bimodal shape visible in 1991 and 1992.

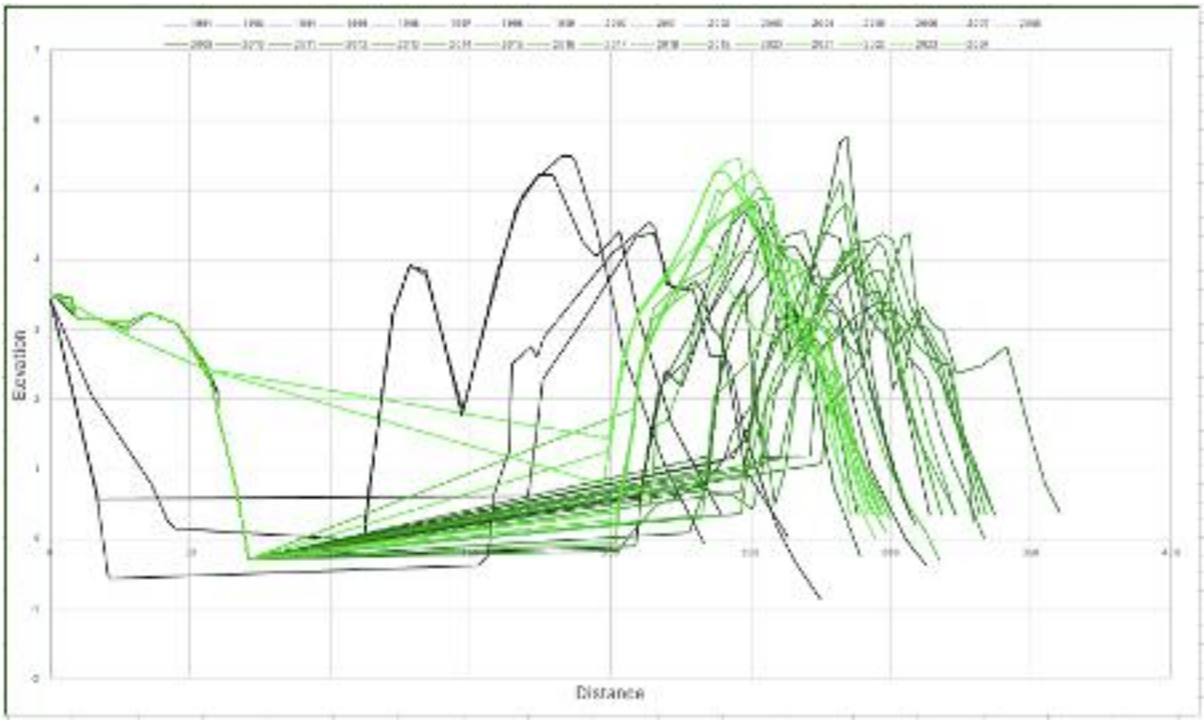


Figure 4. Movement of the barrier from 1991-2024

**3.2 Results - Beaches**

Both beaches north and south of the barrier have shown gradual progradation since the first profiles were recorded in 1991. The beach profiles recorded to the south of the river mouth have stayed roughly parallel to one another, and the slope of the beach has undergone little change (see Figure 5). At an elevation of 3m above sea level (roughly halfway up the profile), the beach has experienced a net accretion of roughly 11m, however the difference between its most landward point (in 2000) and its most seaward point (in 2014) is 34m. The beach has been gradually receding since 2014 and has receded 5m. The beach to the north of the river mouth has experienced a net accretion of roughly 23m (at the same elevation of 3m asl) (see Figure 6). The beach face is highly dynamic, and the data shows the development and disintegration of many berms and other temporary changes in the beach slope and profile such as a berm in 2022 which extended seaward an additional 10m compared to the rest of the profile, however the beach face was completely reformed by the 2023 survey.

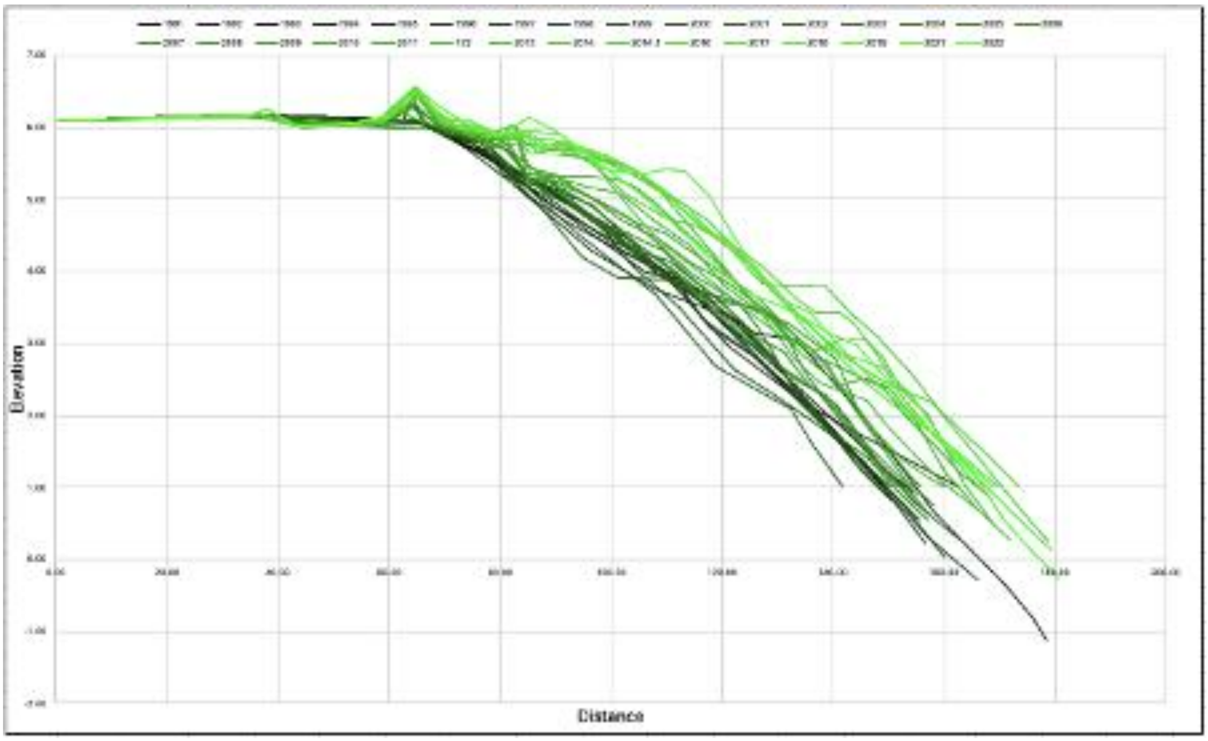


Figure 5. Beach profile from south of the Rakaia River mouth

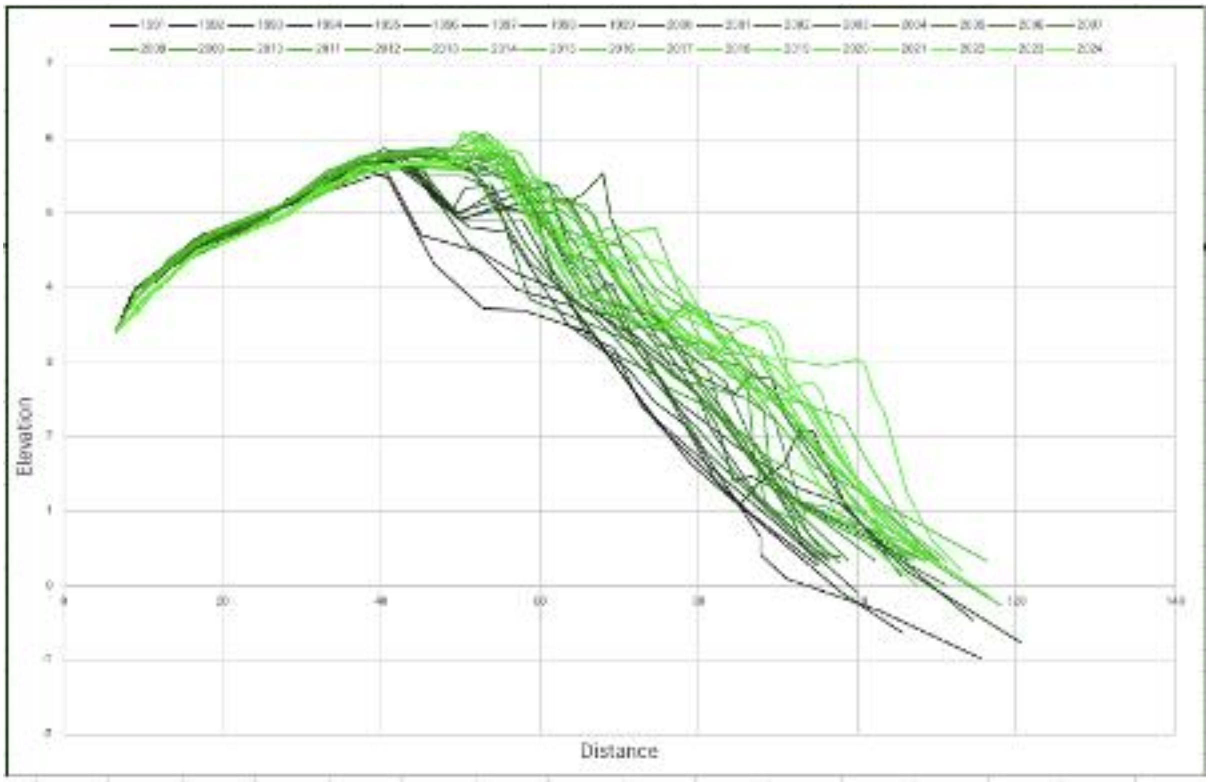


Figure 6. Beach profile from north of the Rakaia River mouth

### 3.3 Results - River bed

The data has shown the bed level of the river has not seen any considerable changes since 1989, which indicates that it is not eroding or infilling with sediment in the long term (see Figure 7). However, it is important to note that there are only four data collection years over the 30+ years our study focuses on and only at one location, so we cannot see smaller dynamic changes in the riverbed. Further, although the net amount of sediment is stable, we are unable to assess the sediment flux nor relate this data to the timing of floods.

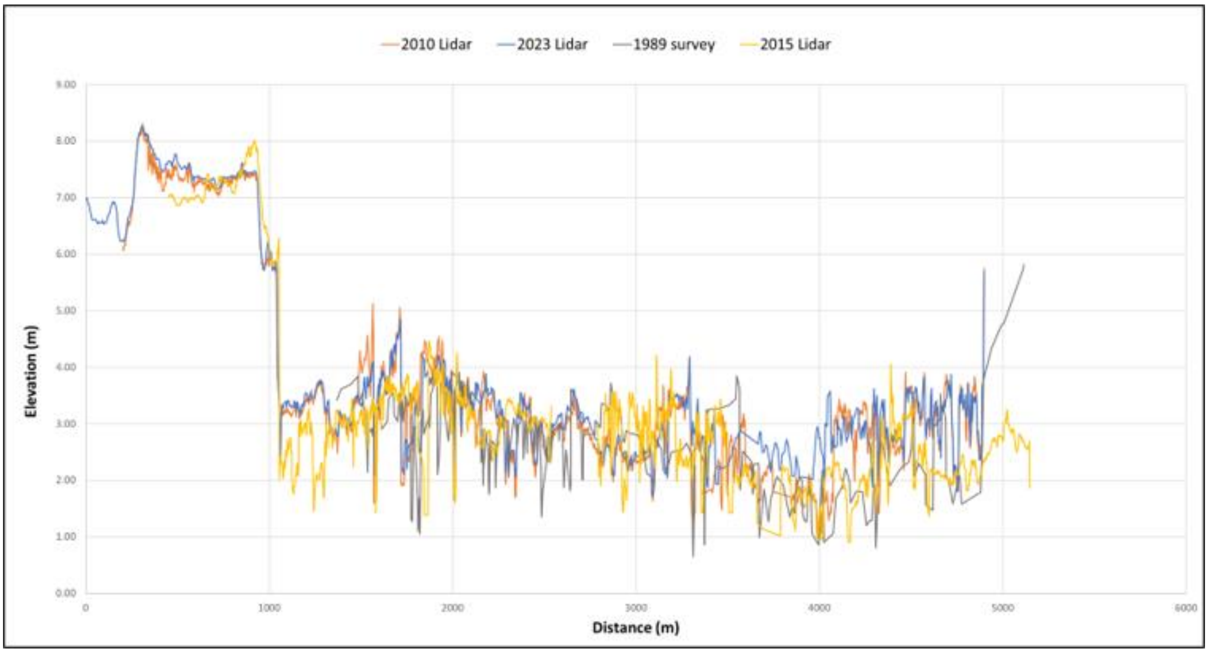


Figure 7. River bed level change from 1989 to 2023


Figure 8; The cross section of the bed level change displayed in ArcGIS

### 3.4 Results – Waves

Directional data from the ECan wave buoy shows that the predominant wave direction is east, consistent with the typical coastal conditions at Rakaia (see Figures 9 and 10). A significant wave height of greater than 2.7m is from the south direction represents high wave energy events (see Figure 10).

There is a high variability in the significant height of waves recorded. This variability is likely driven by seasonal fluctuations, where winter months experience more frequent storm activity due to intensified wind. Most of the data fluctuates between 1 and 3 metres in height with the with the highest peaking at 6.71 m. The peak wave height was recorded in Feb 2002 and there was a barrier profile recorded in Jun the same year. These higher waves than the threshold (percentile line) is the wave energy occurring during storms or big swell events, influencing sediment transport.

The significant wave height data from the hindcast data shows similar fluctuations as the wave buoy data, with typical height ranging between 1-4m and the peaks exceeding 6m (see Figure 12). These peaks as stated above are representative of the higher wave energy events. Additionally, the percentile line (grey) is a threshold for wave heights that are critical for coastal processes such as erosion (see Figures 11 and 12).


Figure 9. Map of Rakaia coastline for wave directional reference.

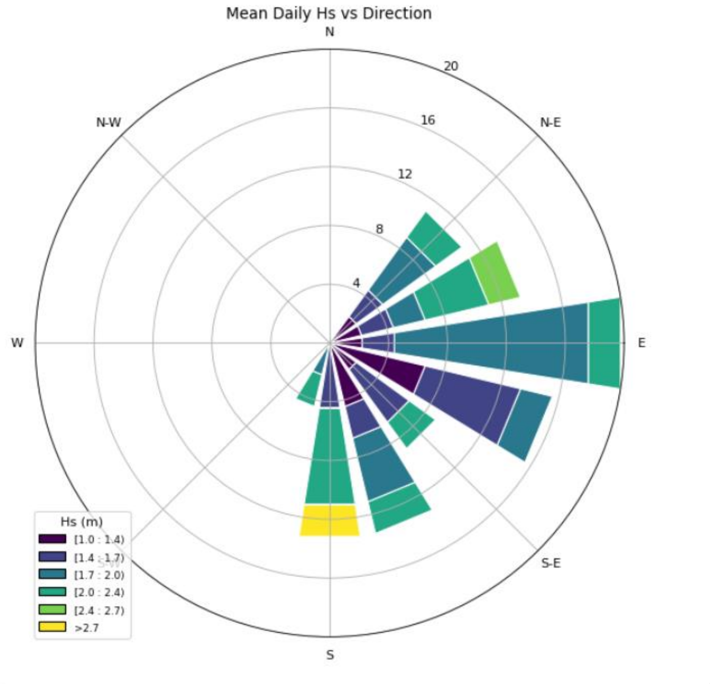


Figure 10. Mean wave direction and wave height displayed on Python wave rose.

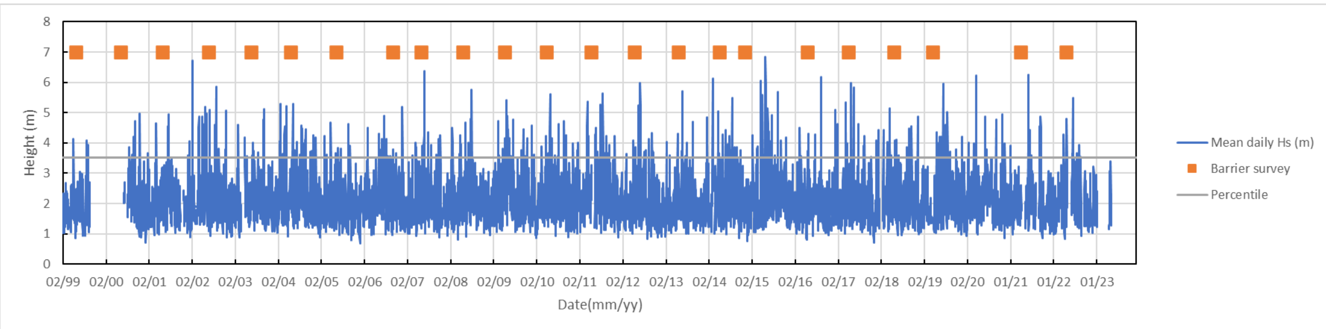


Figure 11. ECan wave buoy mean daily significant wave hight in relation to barrier profile surveys.

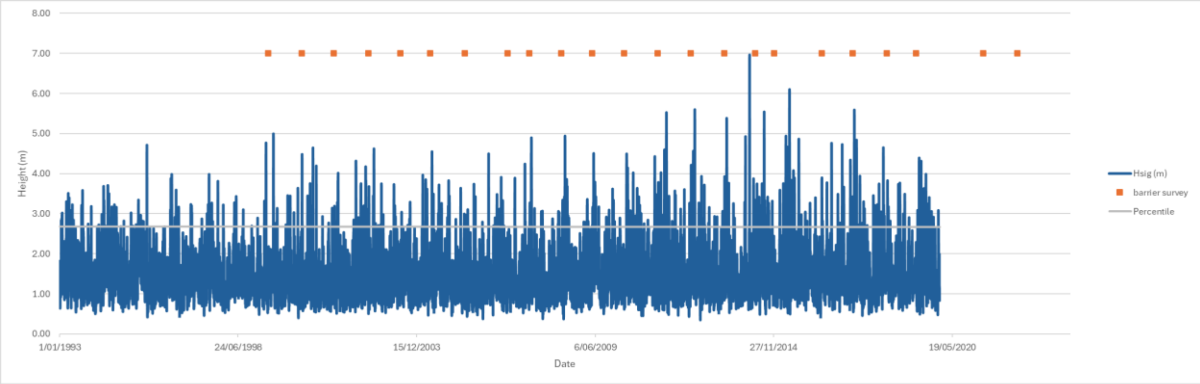


Figure 12. Mean daily significant wave height displayed from the Hindcast model in comparison with barrier profile surveys.

### 3.5 Results - River flow

The river flow at Rakaia has shown significant variability over the period from 1991 to 2023, with several high-flow events exceeding 3000 m³/s, extreme conditions which normally happen in the spring and early summer. Flow events above 2000 m³/s occurred sporadically, with the majority of river flow values generally remaining below 1000 m³/s. Barrier surveys (indicated by orange points) are more concentrated in recent years (2012 onward), suggesting increased monitoring during periods of heightened river activity.

A significant increase in the river flow was found from 2008 onwards, with a p value of 0.032 using an ANOVA analysis. This is reflected in Figure 13, with more consistent and intense peaks in the river flow seen from 2008.

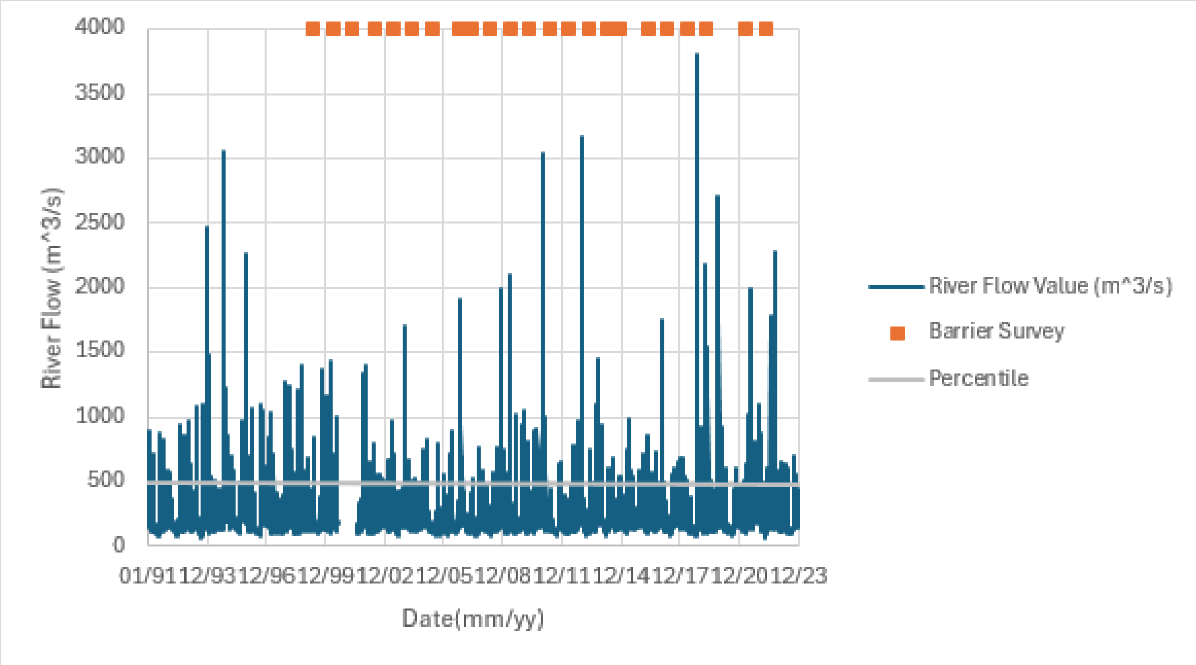


Figure 13. Mean river flow (m3/s) per day at Fighting Hill, Rakaia River, Canterbury containing 95 percentile threshold.

# 5.0 Discussion

### 5.1 Discussion – General

Our research reveals that the Rakaia hapua mouth barrier experienced a shift from progradation (1991 to 2006) to erosion around 2006. However, there are no notable changes to the beach profiles around this time. This may indicate that the change in the barrier position is not solely due to changes in the wave regime or other marine processes, or a change at the beach profiles would also have been observed.

The changes in both barrier crest elevation and barrier shape (i.e. whether the barrier is unimodal or has multiple crests, and the width and slope of the barrier) are due to the balance between sediment transported onto the seaward side of the barrier via marine processes (wave action and overtopping), and the sediment transported to the back barrier via fluvial activity (Matias et al., 2011). If both processes deposit sediment but it does not reach the center of the barrier, the barrier will no longer exhibit a unimodal shape.

The beach to the north of the river mouth is notably more dynamic than the beach to the south, likely due to the fact that longshore drift moves in a south to north direction along the coast (Warrick, 2020). This means the beach profile to the north of the river mouth is impacted by sediment and other river mouth activity, as the current carries any excess sediment expelled from the river mouth north along the coast. The beach to the south of the river mouth does not experience these variable impacts, making it less dynamic. The progradation seen in both beach profiles could be due to a coastal cell/compartment creating a localized current which allows sediment from the river to replenish both beaches (Bray et al., 1995). Alternatively, it could be due to sediment being transported onto the beach from offshore or further south along the coast, or a combination of these.

The Rakaia hapua is more difficult to comment on than the barrier, as there have been far less, if any, data points taken in the hapua itself. Therefore, we can't conclude anything about the depth of the hapua at this stage.

### 5.2 Discussion - Waves

Southeast to east swells are prevalent at Rakaia due to the influence of the Pacific Ocean. These swells, often driven by low pressure systems originating in the Southern Ocean and polar regions, significantly impact nearshore wave dynamics and particularly sediment deposition and erosion (Gorman et al., 2003). Higher wave energy events could impact on the sediment transport at the river mouth and the barrier. During significant wave height (Hs) periods, waves generate powerful currents and longshore drift, leading to the erosion of the barrier and redistribution of sediments along the coastline (Masselink et al., 2014). This repetitive process during a storm event will significantly alter the morphology of river mouth and barrier (Masselink & van Heteren, 2014). The frequency and intensity of such events play an important role in the dynamic equilibrium of the coastal environment, contributing to both accretion and erosion cycles over time (Brocchini, 2020). Wave heights surpassing the threshold ($95^{th}$ percentile) will have substantial impacts on the morphology of the beach and the barrier, reshaping these features over time. The hindcast model (seen in Figure 12) shows supporting evidence towards the wave buoy data as it was taken from -44.0°,172.3° which is closer to our study site. Wave buoy data was collected from banks peninsula and therefore has limitations to how accurate the results can be for the Rakaia coastline. As both the ECan wave buoy and the Hindcast model show a similar result, wave action does play a crucial role in sediment transport and coastal erosion at the study site. This data collected could be used as an insight into flood management or erosion rate knowledge.

These higher energy waves create erosional patterns over extended periods of time. Looking at wave height alone we can understand that the erosion processes of the shoreline will occur as the higher waves overwash the beach and barrier (Flores et al., 2016). Although within a dynamic environment natural processes are interlinked effecting each other constantly. In combination with the high energy events discussed above affecting the barrier and the beach it is influenced heavily by the direction of these big events. Sediment transported from these high energy events will alter and reshape the river mouth and barrier this could then affect the flow dynamics creating feedback loops (Mortlock & Goodwin, 2015). By having the beach profiles on the graph, it highlights the potential profiles that could show changes due to wave action (Figure 11 and 12). Important to note that the surveys are not aligned exactly with the high energy events. This could indicate limitations to the ability to capture the data of their influence. As the data was collected from a site further up the east coast there are other factors that could affect these results. The climate change and antarctic oscillation has impacted the wave action in southern hemisphere significantly the wave power has been increased 2.6 times above the world average level (Liu et al., 2024).

### 5.3 Discussion - River flow

Changes in river flow can influence how much sediment is transported and deposited at the river mouth (Yang et al., 2015). Increased flow rates can lead to higher sediment transport, potentially building up the river delta and altering the barrier.

Before analysing the river flow data, we expected that there would be a significant decrease in the river flow from 2008 onwards due to the introduction of irrigation in the Rakaia area removing large volumes of water from the river and therefore decreasing the flow (Heiler, 2008). However, this was not seen in our data, and we found a significant increase in the river flow from 2008 onwards. This does not align with our predictions and therefore would require further research around why we see an increase in data, possibly due to the position of the gauge low in the catchment.

However, as explained earlier the barrier has been retreating since 2008 and this increase in water flow could be a significant driver of this. The enhanced river flow can lead to redistribution of sediment in the barrier and deposit more sediment on the hapua side of the barrier, supporting the finding of the barrier retreat since roughly 2006. According to Lorenzo-Trueba & Ashton (2014), sediment must be supplied both onto the front and the back-barrier to facilitate barrier migration inland.

**5.4 Discussion – Bed level**

The riverbed level has remained at a similar level throughout the study period. This indicates that the riverbed near to the mouth has not experienced significant erosion or progradation over the study period. This means the sediment supply and river flow have been in equilibrium during the study period, indicating that the increase in average river flow around 2008 discussed above was accompanied by an equivalent increase in the sediment supply. The bed level remains at a similar level, this shows the riverbed system was adjusted by the environment. The 2008 river flow data showed that the flow has been increased which in a normal scenario it will increase the amount of the sediment that's been transported down to the river mouth, which in this case was not stored in the riverbed, as no accretion of the bet was seen. This is supported in the literature, with Neverman et al. (2023), claiming that some areas of New Zealand will see increases in fluvial sediment flux of up to 233% due to the impacts of climate change.

# 6.0 Future research

In terms of future research, there are several areas where this investigation could be expanded.

The switch from barrier progradation to erosion is worth more research to determine what caused this, as it could serve as a proxy for the future to determine if the barrier will keep receding or not.

Future research could also look more thoroughly into changes in the hapua and how this might affect the community and local environment. A possible approach would be to access LINZ digital elevation data for the hapua area, although this would be restricted to the years 2016 and 2023, as these are the only years with publicly available elevation data for the area. Impacts on the natural environment and the ecology of the area could also be investigated, as this report has largely focused on the impacts of flooding on the Rakaia Huts community. However, it would be difficult to find relevant long term ecological data, and thus would likely involve much primary data collection.

Finally, future research could also consider the impacts of climate change and human influence on the barrier system. Climate change, including sea level rise and extreme weather events, will impact various factors discussed above, such as waves and overwashing, river flow and sediment supply. Recent water take for irrigation from the Rakaia river is another change the system is currently facing, and may decrease river flow, which will impact the sediment supply to the barrier.

# 7.0 Limitations

The use of pre-collected data presented several limitations, such as concerns with data completeness, accuracy, and temporal resolution (Harmel et al., 2006). Due to us not collecting data, the ability to modify methods was limited. Also, the site selection could have bias, as we choose data based on the site we could access, and this could skew the results. To overcome these limitations, certain methods like the use of drone-based aerial imaging and LiDAR technology gather repeat high-resolution data, allowing a better understanding of both the barrier and beach profiles. This approach would enable a more detailed analysis of the physical changes over time. Finally, partnerships with NIWA and ECAN provide access to recent better, customized datasets that are more tailored to the specific needs of the research.

By using GIS analysis, it could enhance the research by incorporating 3D modelling and geomorphic change detection techniques can help to visualize the of barrier and river changes easier, and also in 3D. This can improve the understanding of sediment dynamics and coastal processes. Finally, the use of RStudio can help with data validation, statistical testing, time-series analysis, and regression modelling, strengthening the conclusions drawn from the research.

The time constraints placed on this project have been a large limitation on the in-depth research that this study needed. With the introduction of a longer timeframe, the research could have been expanded with further consulting with community partners and conducting a more extensive study of the barrier and river system. This would allow a deeper understanding of the social, environmental, and cultural aspects of the Rakaia River.

## 8.0 Conclusion

The developmental changes of the Rakaia River mouth barrier have created several different challenges for future management and the surrounding community. The study uses data collected over the last 30 years and shows how both natural and human-induced factors can influence the barrier. The findings showed that the barrier has had a gradual progradation since 2008, with adjacent beaches showing a gradual retreat. The wave action from the east of the Rakaia River has a significant contribution to barrier erosion, and the increase river flow since 2008 may also be linked to the retreat. These results can help to inform flood management strategies to help to protect the area's cultural and social significance.

Therefore, the research highlights the need for management strategies that will help the different environmental changes. Future research should investigate the different causes of the barrier’s retreat, the impacts on hapua and the larger implications of climate change. This knowledge can help to support proactive strategies to preserve the region for future generations.

## 9.0 Acknowledgments

We would like to recognise those who have supported this project and contributed to reaching our aims. Firstly, our community partner, Bill Southward, for valuable insights to the environment of the Rakaia region. Special thanks to Sarah McSweeney for her guidance and assistance in making the project achievable. Lastly, we extend our appreciation to Jess Sullivan from Selwyn District Council Emergency Management, for providing key information on flooding events and community response.

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